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FINAL REPORT

# Maximizing Storage Stability of Foods to be Used for Resupply in a Controlled Ecological Life Supply System: Evaluation of Research

(NASA-CR-158846) MAXIMIZING STORAGE STABILITY OF FOODS TO BE USED FOR RESUPPLY IN A CONTROLLED ECOLOGICAL LIFE SUPPLY SYSTEM: EVALUATION OF RESEARCH (Massachusetts Inst. of Tech.) 187 p HC A09/MF A01

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## I. Introduction

Foods are plentiful in America. The commercial marketplace for food abounds with quantities and varieties of fresh and processed food products. Most Americans have come to believe that a plentiful food supply is a worldwide situation that is unexceptional and always will be so. The exact opposite is true. The history of mankind and the facts of life today are that the majority of people on earth struggle to maintain sufficient intake of nutrients to sustain life. For most people on earth today, the obtaining of food is the major technological and material challenge of life.

This abundance of food in the United States has given rise to a series of myths. One of such myths is that in order to satisfy the needs of any special feeding situation the only procedure necessary is to select the appropriate items from among those available in the commercial marketplace. This myth is untrue. The facts are that foods in the commercial marketplace have been developed to meet specific criteria which are quite different compared to criteria of foods systems other than those designed for mass supply of huge populations.

The fallacy of the myth that proper selection from the commercial food supply will satisfy any specialized food situation has been repeatedly demonstrated. Major problems in adapting commercial foods to specialized situations have been encountered in our society. The military situation and history of the United States military food supply system is a classic example. Among specialists it is well recognized that military food supplies which require an optimum storage

life and distribution under noncommercial conditions also require foods to be produced to unique specifications. A similar experience has been gained in NASA regarding support of the food systems for projects Mercury, Gemini, Apollo, Skylab, and Apollo-Soyuz.

In more common everyday occurrences the failures in attempts to adapt commercial foods to specialized feeding situations has been repeatedly demonstrated in the development of camping systems and outdoor recreational supply equipment. Successful life support systems for explorers has only resulted from the development of highly specialized foods. The NASA achievement in food systems for projects Mercury, Gemini, Apollo, and Skylab are major milestones in the development of highly specialized cost-effective foods to match the specific demands of the special life support system criteria.

The variety of foods and types of foods available in the commercial marketplace result primarily from sets of factors characteristic to the commercial marketplace. Those marketing factors are analyzed and applied by evaluating primarily 4 major considerations:

I. Safety.

II. Compliance with government regulations.

III. Long-term marketing advantage for the product.

IV. Continued availability of bulk quantities of the ingredients (i.e. profit stability).

With the exception of safety, none of the major factors which determine the items available in the commercial food supply are directly applicable to the resupply of the controlled ecological life support systems. The first step in identifying food for specialized situations is to identify the performance criteria necessary to such foods.

Foods developed for retail marketing have largely been devised after large scale population marketing surveys which are interpreted by

statistical analyses. Such statistical interpretation and surveys are meaningless for the individual consumer. They apply to the mass market. They are geared to maximum efficiency in the mass marketplace. They work effectively for predicting market penetration, supply distribution, and profits in mass scale supply systems. Food items available on the commercial marketplace must be subjected to a highly individualized selection before they can be fully integrated as part of a normal diet.

The constraints and considerations inherent in the technical development, formulation, and provision of food items for the large scale commercial market are not necessarily compatible with the major criteria necessary for foods for a closed ecological life supply system. Most commercial food items are designed, developed, and formulated to be suitable for mass production and mass distribution with relatively rapid turnover in the distribution system.

Most commercial food items are marketed with the concept of targeting the supply system such that an average of 6 weeks is required from production to consumption. This relatively short time in the distribution system is necessitated primarily from economical considerations. The value of such food items in the supply system during the marketing process is very high. To maximize cash flow the producer is motivated to minimize the value of his commodities in the supply system. The greater the duration of time in the supply system the greater the need for cash investment on the part of the producer. Therefore, there is a maximum incentive to move food through the commercial supply system rapidly in order to reduce investment in inventory. The modern food distribution system for commercial purposes is based largely on this economic principle. Economic survival depends upon it. Therefore, there is a minimal consideration in commercial practice given to extension of shelf life beyond the optimum necessary for maximizing market profit.

It is a fact that the major predominating factors which govern the production and marketing of the majority of commercial food items tends to favor food formulations and food production and packaging procedures which are ideally suited to production, distribution, and sales to large populations with a maximization of profits. In a free market economy, the most apparent "benefit" from the consumer's viewpoint is a minimization of the price at the time of initial purchase. However, these factors are rarely compatible with minimizing total systems cost. These factors are virtually never compatible with the development of food items which can be integrated into food systems designed for other requirements--such as a controlled ecological life supply system (for military supply systems, for support of exploring expeditions, camping systems, or other special use systems). In fact, the success of the mass production and distribution system in the U.S. has selected against specialized foods which might be suited to other specialized needs. The net result is that U.S. foods are highly specialized for mass production, distribution, and sales. They are poorly suited to optimization in other systems. Optimization of foods for other systems requires that they be specially designed to take advantage of all the potential inputs from modern food engineering, nutrition, food science, and food technology.

Another set of important factors governing food types and composition in the commercial marketplace involves government regulatory provisions. Foods entering the commercial marketplace must comply with regulatory provisions which are not designed for compatibility with requirements for specialized food systems in closed life supply systems. These regulatory provisions are designed to protect the mass food market. For example, many commercially processed foods (most common items) are designed by use of a system of Standards of Identity which are predicated

on arts, technologies, and practices long standing in society. They are not necessarily the "best" technology. These are therefore economical and efficient for mass production primarily because of standard commercial practices. However, it is well recognized that technology can now provide improved products for individualized special situations such as closed life support supply systems. This special technology would not necessarily be suited to the commercial marketplace, and therefore, has not been fully commercially developed. Compliance with such government regulatory provisions is one of the many factors which restrict the spectrum of available foods which might otherwise be provided for specialized systems such as controlled ecological life supply systems.

In considering extended manned space mission it is necessary to evaluate the potential for regenerative life-support systems including those with limited as well as complete closure. Analysis of problems related to nutrition, diet, and food processing showed that a number of long-range research studies will be required if a fully regenerative food ecology is to be developed. The questions to be answered in such a long-range program include the following broad categories (each being a parent to a host of subsidiary questions).

A. Nutritional requirements of humans on a limited variety diet, especially while operating under conditions of space environment.

B. Capability of agriculture, waste disposal technology, and subsidiary technological operations to attain a close-cyle operation adequately supplying the life support needs for the expected population.

C. Need for buffering capacity (storage or resupply capability) to accomodate expected or unexpected breakdowns in regenerative capabilities.

D. Development of "industrial" base for conversion of animals and synthetic materials into "food." This will involve development of food processing, food preparation, food storage, and waste disposal systems adapted to the unique requirements of space colonies.

E. Development of industrial support for the food processing

operations. This includes the capability for production of necessary chemicals, energy, and machinery for the space habitat "agribusiness."

In view of the complexity and uncertainty associated with these problems, another option which should be considered is the total or partial resupply or stocking of food for the space colonies. This series of options might range from resupply of a portion of the diet (for instance of animal-derived foods and of all vitamins and some other essential nutrients with the calorie requirement met primarily by local production) to resupply of all of the food with the local regenerative system limited to water and oxygen.

In order to develop these options, research will have to be undertaken on several aspects of food resupply and storage. Delivery system development, integration of regenerative and resupplied portions of the diet, and storage stability of foods in forms suitable for delivery are among these problems. The present proposal is addressed to the analysis of research needs pertaining to storage stability of foods capable of providing a complete diet and processed in a manner suitable for delivery by space shuttles.

The present evaluation of the state of art and of research needs in the area of storage stability of dehydrated foods was undertaken with the following aims:

A. To review existing knowledge of stability of foods processed and packaged in a manner suitable for resupply by means of space shuttles.

B. To outline research required in order to close the existing gaps in the knowledge of stability of foods.

C. To outline research required in order to determine what processing, packaging, and storage systems will maximize the stability of foods.

D. To outline research required in order to develop accelerated tests to allow prediction, simulation, and optimization of storage stability of foods.

In each of the above aims the stability of foods is used to mean lack of changes resulting in unacceptable changes in the following essential attributes of foods:

1. Organoleptic acceptability (flavor, taste, texture, appearance).
2. Absence of factors deleterious to health (toxins, pathogens, carcinogens).
3. Nutritional value.
4. Functionality (for instance, capability for rehydration and dispersion).

The study included a critical literature review, as well as evaluation of experience gained in two recent workshops devoted to research needs in connection with development of closed ecological life support systems.

The report has the following parts in addition to this introduction (Section I):

Summary Report (Section II)

Detailed Report (Section III)

Appendix (Section IV)

# II. Summary Report

## A. Overall Plan

The overall plan (Figure 1) is based on the view that several phases are required for research and development, and testing of advanced technology before a closed ecology life support system (CELSS) is to be established in space.

This study is concerned with stability of dehydrated foods to be used for resupply in a controlled ecological life supply system. A rationale is furnished for research and development in stability and utilization of dehydrated foods as a resupply component. To elucidate related problems, a brief description is also provided of research needs in some of the other fields.

Research needs were divided into: essential research and suggested research. The difference between these two groups is based on overall priorities.

The research and development plan reflects an assumed three-phase program. Phase one starts with the research on life support systems for future spacecraft. The initial launching efforts will start the second phase. This phase will exist during the period required for establishment of partially closed life support system. The third phase will be initiated when CELSS begins to provide some of the food but will still depend on substantial resupply from earth. The creation of a substantially closed CELSS will start a new stage in which food is no longer to be supplied from earth. This event will end phase three. In each phase, main research and development needs are described (Figure 1), however, only

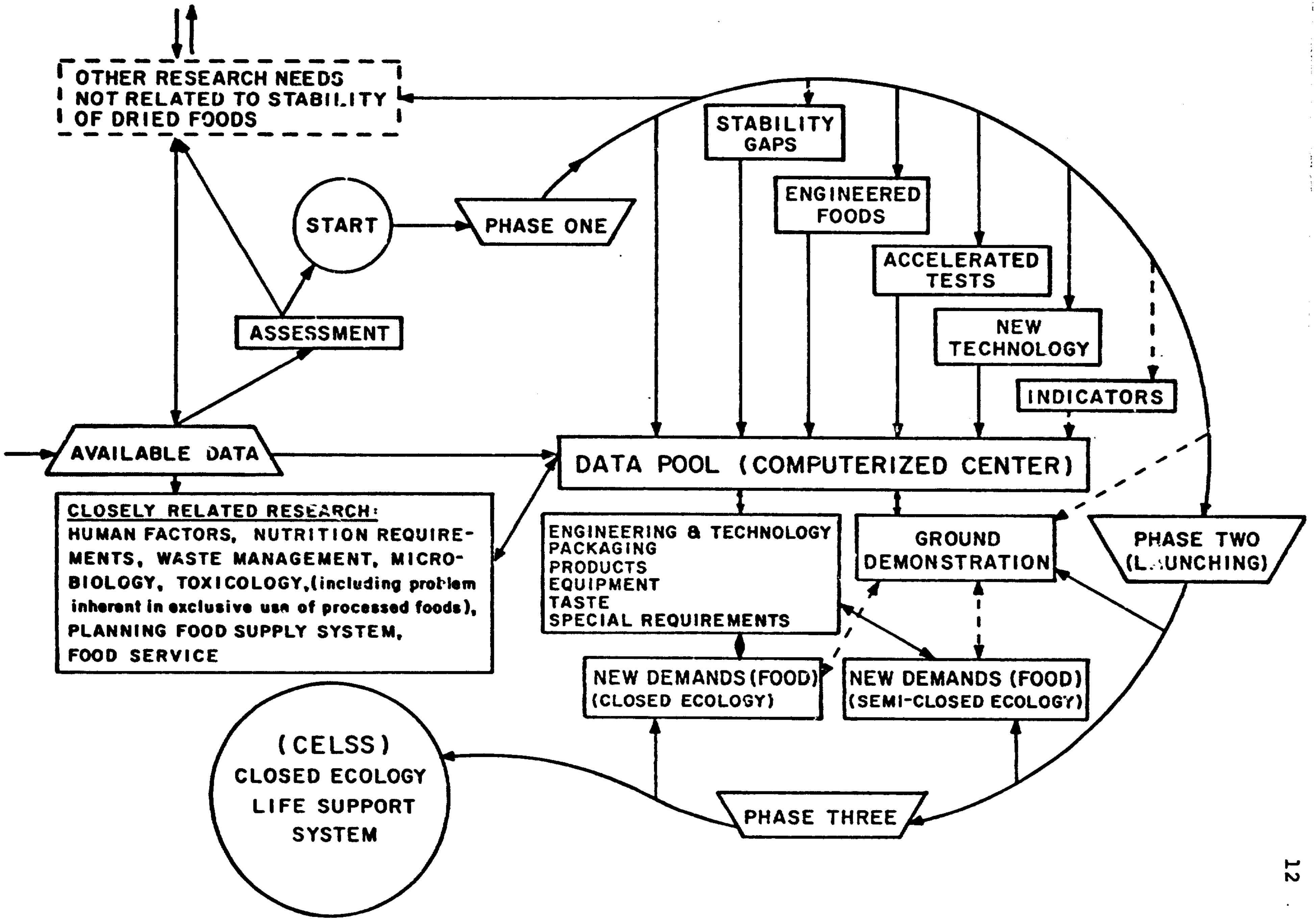


Fig. 1 - Schematic representation of research and development for the CELSS food system

phase one is described in detail.

In conjunction with this three-phase program we believe a simulation period to be a necessity. This period is required for the evaluation of the knowledge and information gained up to and during phase one, and as a tool for predicting further scientific challenges to be faced in CELSS. This simulation period will be used to elucidate the unsolved problems and furnish final answers to serious problems anticipated by the creation of a large artificial ecosystem. Furthermore, the simulation will provide the ultimate tests and understanding before a large-scale implementation of CELSS in space is to take place. The size and duration of the ground demonstration remains to be determined. It is assumed however, that basic problems must be attacked on earth first, then in near space orbit. Only after successful self-contained systems have proven feasible on earth for some time, ought such a system be launched.

B. Research Needs

1. Development of information on stability of important food items for which such stability data are presently not available, and improvement of stability for products which are currently not adequate

A survey of literature on available stability data (Section IV) has disclosed gaps in the knowledge of specific types of dehydrated foods suitable for inclusion in the resupply system. Many of these foods are sufficiently important, and the knowledge

about stability of their potential substitutes so limited, that it will be necessary to conduct stability studies to determine their stability under suitable conditions.

We have conducted an extensive survey of literature with respect to storage stability of dehydrated foods. A great deal of information has been presented in the literature but evaluation of their data is difficult. Standard methods have not been used to determine food acceptability, and storage conditions varied from product to product. In addition, some of the early studies, although useful from a qualitative point of view, reflect the lack of modern technology necessary for quality retention.

Tables showing a detailed analysis of the stability data developed in the literature search will be included in the "Detailed Report". We are including in the present Summary Report a summary table (TableII-1) presenting the observed maximum storage life.

In order to facilitate the evaluation of this data we have divided products for which the stability data were found into two categories: a) products which meet the U.S. Army requirement for stability of at least 6 months at 100°F, and b) products which meet the requirement of stability for at least 2 years at 70°F. It needs to be reemphasized that absence of items from this list does not necessarily mean that they do not meet above requirements, since they may simply not have been studied. Furthermore the stability of specific products under specific conditions may not guarantee

stability of similar but not identical products and conditions.

Products having an apparent 6 months stability at 100° are shown in Summary Table II-2. Products having a reported shelf life of at least two years at 70°F are listed in Summary Table II-3.

Evaluation of the data referred to above discloses that there are gaps in information concerning stability of dehydrated foods, which will require additional research for their resolution. We summarize these gaps with reference to specific classes of products.

Fruit and vegetable powders

Many of the studies reported in the literature, have not fully considered conditions favoring storage stability. Factors that require especial consideration include adjustment of residual moisture content by extended drying time or in-package desiccation; controlled use of heat in the preparation of a product, which would include not only heat applied during the process itself but temperature for conditioning; use of additives such as sulfur dioxide, antioxidants, anticaking agents and drying aids and finally, packing in an inert atmosphere.

We consider that research objectives should be focused on a) enlarging the number of selections and b) improving the quality of fruit and vegetable powders currently available. Improvement can be done not only by modifying process variables but also packaging conditions. There is need to improve quality through increased flavor and nutrient retention. With

respect to storage stability proper the need is primarily for definition of optimal moisture content.

In regard to storage stability of freeze-dried powders, substantial information is missing. Information currently available presents the drawback that in many cases, either the time of storage was not sufficient to determine product failure or storage conditions provided were definitely not the ones that would favor quality retention. The area of vegetable powders requires especial consideration. Most of these powders constitute the raw material for dehydrated soups. Dehydrated soups have been found to present relatively poor storage stability when kept at 100°F which is the temperature widely used as a test of long term storage stability at lower temperatures.

Fruits

A large number of fruits have been successfully dehydrated. Osmotic pretreatment combined with freeze-drying has been found to give products with good texture, flavor and color characteristics. These products were found to be acceptable when consumed in their dehydrated form. Upon rehydration they have poor texture. More research is still needed to obtain products that are satisfactory upon rehydration. From the point of view of storage, a detailed study has not been carried out for most of them. The number of selections that pass the arbitrary storage requirements are limited to 3 or 4.

Vegetables

Dehydrated vegetables are available on the market for a large variety of applications. Applications of these products

include soup mixes, canned foods, processed meats, baby foods and others. Most dehydrated vegetables have been processed using air-drying. As in the case of fruits, a disadvantage of these products is the low rate of rehydration. Depending on the particular use of the dehydrated vegetables, slow rates of rehydration might not be of any critical importance.

Difference between air-dried and freeze-dried vegetables are noticeable not only with regard to texture but also in regard to flavor and color. These differences arise mainly from the shrinkage which occurs during air-drying but not during freeze-drying. The selection of air-drying or freeze-drying as the most suitable method for dehydration seems to vary from commodity to commodity.

The advantages of freeze-drying in the dehydration of vegatables have been questioned in many cases. Freeze-dried vegetables not only are costly as far as processing is concerned but also are highly demanding in regard to packaging. As mentioned earlier, if adequate packaging is not provided, their initial quality will quickly deteriorate as due to high sensitivity to oxidation.

Our literature survey has shown that most dehydrated vegetables that pass the U.S. Army requirements are either air-dried vegetables which are less oxygen-sensitive and less hygroscopic, or freeze-dried vegetables for which special packaging, such as 5% hydrogen in nitrogen with a palladium catalyst, was provided.

The area of dehydration of vegetables has been amply covered. Research is greatly needed in the area of dehydration of leafy vegetables. In regard to storage, a great deal of information in available for air-dried products. Including air-dried products, the number of vegetables passing the Army requirements is not as limited as in the case of fruits. More information is still required in the area of storage of freeze-dried vegetables since they have not been as thoroughly studied.

Prepared foods

Approximately twenty meats or meat substitutes have been prepared and kept in their dehydrated form for over a period of 6 months at 100°F. Further research is required, however, to increase the number of selections for main course entrees. An increase in the number of choices would certainly rule out the possibility of a monotonous diet. Storage information has not been disclosed for a number of commercial products for campers but they are reported to have an excellent shelf life when packed in a nitrogen atmosphere. Some of these products include: chili and beans; beef chop suey; shrimp creole; beef stroganoff; noodles and chicken; macaroni and cheese; lasagna with meat sauce; beans and beef franks; potatoes and beef.

An area that requires special attention is the area of dehydrated soups. Dehydrated soups for which information is available have been found to be unable to retain good quality for more than three months at 100°F.

Fish, Meats and Poultry

Information relative to dehydrated fish is very limited. Most fish varieties have not been successfully dehydrated and/or stored. A few exceptions such as salmon and tuna, have both good initial organoleptic properties and good storage stability.

Although some meat and meat products have been dehydrated and give good color, flavor and nutrient quality, good texture is rarely achieved. Toughness and dryness of the product upon processing, are problems that intensify during storage. Fish products also present difficulties associated with loss of texture and water-holding capacity.

Literature clearly shows that oxidation is a major shelf-life limiting mechanism. Thus storing at low oxygen pressures, which may be relatively easily accomplished in space may give excellent shelf life. However, storage information is missing for most products when exposed to minimum amounts of oxygen, but some information is available for most products with respect to effects of water activity and of temperature.

2. Developing a system for generation and utilization of stability data

Repetition of searches and of tests when new combinations of foods or conditions are to be used is expensive, and wasteful. There is an urgent need to develop an information data bank center which will collect published and unpublished information on food stability, engineered foods, nutrient content and retention, food processing, toxicology and other related subjects.

The proposed center will be used for disseminate information on stability of specific food items and other related topics after scanning analyzing and assessing the information. Moreover, the center will be used for collecting all the information furnished by future projects funded by NASA and any cooperating agencies, thus providing an important management tool.

This center should be available for retrieving information to governmental, industrial and academic users. It is expected that if NASA takes a leadership role in promoting such a center the costs of its development, and operation may be borne subsequently by users and that industry will be willing to contribute data on a reciprocal retrieval of information privilege basis. This last premise, however, remains to be tested. It is further assumed that an appropriate location for the center is one of NASA's research centers.

Collection of reliable stability data on food products to be stored for long periods is a difficult task. It is impossible to

conduct stability tests for all foods under all conditions, due to the large variety of foods and of potential conditions of storage. Moreover, the quality requirements may change as the results of ground demonstrations and flight tests. It is therefore necessary to promote development of techniques which will provide such information when needed in relatively short time, with relatively less effort than is necessary for full-fledged stability tests.
Accelerated tests are reviewed in section III-B.

3. Engineered Foods

Providing a sophisticated and varied food supply for the limited facilities available in the environment of space habitats, in conjunction with dietary requirements is a difficult task. Moreover, the need to optimize nutrient balance and minimize food system mass, while providing an appetizing diet of variety and quality even remotely similar to that, which we enjoy on earth presents immense difficulties. One potential solution is the provision of engineered foods which are produced by incorporation of engineered foods which are produced by incorporation of natural and/or synthetic components into systems having desired nutritional organoleptic and stability characteristics. Since organoleptic properties are by far the most important stimuli, for making nutrients into foods, development of organoleptic equivalence of engineered foods will allow utilization of a variety of nutrient sources no matter what their origin. Furthermore, organoleptic equivalence also

permits, for the first time, the construction of nutrient sources to the specification of human needs rather than dependence upon the vagaries of natural products.

Due to their palatability, high caloric content per unit volume and weight, adaptability to a nutritionally balanced formulation and inherent convenience of packaging, storage and utilization, these engineered foods seem perfect components of the space diet.

Further details on engineered food are given in section III-C.

4. New technology

Efforts are needed to improve technology of food processes for high quality dehydrated foods. New technology such as compressed freeze-dried foods which offers numerous space-saving advantages and exhibits remarkably normal texture properties as well as reduction cuts on packaging storage and transportation are highly recommended for further thorough research. Other methods such as continuous compression freeze-drying, microwave heating and drying and other drying methods are to be considered.

Another aspect to be investigated and considered is the usage of space conditions in design of new drying processes to be used in the space colony, and the effect of hard vacuum of food storage under space conditions on shelf-life.

Methods of utilization of food for feeding of the space habitats are required. The sizes of optimal packages to meet the specification and requirement of mass feeding

in the CELSS are still unknown. Not all these aspects may be approached with terrestrial experience and knowledge. Some aspects of related problems are yet to be solved only by simulating space conditions. A short review of recent development in drying processes is given in section III-D.

5. Indicators

Even with perfect storage stability information, and accelerated tests it will be necessary to assure absence of deterioration in specific lots which may undergo storage conditions significantly different from those expected. Since it is likely that quality control personnel and facilities will be extremely limited in the space environment, the indicators will provide the required information and warning.

Furthermore, if a foolproof system is desired and is to be provided for the space habitats it is highly recommended that a new approach be taken in which efforts will be focused on development of a new era of indicators. These indicators may be combined with not only the quality changes of the food stored (i.e., nutrients, flavor, oxidation, etc.) but also with the appearance of toxins and other health hazards. Due to the complexity of the food system, the complicated deterioration reactions involved, and the low concentration of the toxins, further major research is required to solve this problem.

However, based on available knowledge on indicators (as reviewed in section III-D), the proposed research on indicators was categorized only as suggested research. This

decision may be explained by the long time required for designing the new era of indicators recommended, and due to the fact that some other sources of information (such as stability data and accelerated tests) may be used.

C. Other research needs related to dehydration foods

1. Human factors

Impact of human factors on food requirements is one of the most important fields which requires further research. Eating preferences show that even in slightly modified conventional environments, such as in military operations, tastes and eating preferences may shift. Thus, it may be assumed that in extra-terrestrial environment, human preferences and tastes will change in response to new conditions. Ability to anticipate these taste shifts and new human preferences and requirements is highly desirable for proper formulation and selection of space diets. The relations and interrelations of space conditions food supply (high volume of dried foods) and human factors have to be carefully considered and evaluated before any dietary theory is to be accepted for purposes of planning.

2. Nutritional requirements

Development of suitable scenarios for nutritional demands, adequate for space environment and acceptable for special CELSS requirements, is one of the major areas in which further research is required. Unknown effects of prolonged existence is space, and under special conditions of CELSS environment require a nonconventional approach

for designing of properly balanced diets. Testing these diets may require multigenerational animal experiments under simulated space conditions and environment.

The effects of CELSS on nonconventional terrestrial nutritional requirements have to be evaluated considering the foods and methods of production, especially due to the high volume of dried foods. Attention should be focused on designing the criteria to evaluate the acceptability of the diets for various duration of mission periods. It can be assumed that the longer the period in space, the more complex will be the diet requirements. The design of advanced foods (such as engineered foods) and diets, demands precise information on minimal requirements and tolerances for human needs of trace minerals and other nutrients. These requirements will also mandate an efficient monitoring system for mineral and nutrient tolerances. The effect of the diet should be tested from other aspects as well. The need for supplying the diverse diet needed to meet the psychological requirements magnifies the problems of meeting the metabolic requirements.

3. Waste management

A capsuled description of some of the research problems in waste management which are coupled to food technology follows:

a) Waste characteristics and utility of non-edible components of the dehydrated supplies, and of non-eaten components of the dehydrated foods.

b) Methods to reclaim water aimed at water reuse for human consumption and food processing (including rehydration of re-supplied dehydrated foods).

c) Pollution control of the food systems.

d) Controlling compounds that are not readily recycled but have to be used in food as additives.

e) Proper delivery and removal of nutrients and minerals during their cycling.

f) The hazard associated with toxic substances.

4. Microbiology

In order to sustain a complex artificial ecosystem, the micro-organisms necessary for maintaining the biological cycles and the diverse organisms involved in decay of food chains would have to be established, as would a variety of other micro-organisms required for the flourishing of some plants. Other aspects which may be involved are:

a) Microbiological problems in the ecosphere of the habitat resulting from utilization of the dehydrated foods as a resupply system, and specific microbiological requirements to be imposed on the production of the dehydrated foods.

b) Problems related to the long term stability of the ecosystem, and the "desired" micro-organisms required for providing this stability.

c) Undesired micro-organisms that would inevitably penetrate the ecosystem with the food resupply.

d) Food production based on microbial fermentation.

e) The hazard effect related to the use of chemical biocides

(chlorine, bacteriocides, fungicides, algacides, pesticides, and others) used as preservations in foods or as a control agent must be investigated before recycle is used.

5. <u>Toxicology, including problems inherent in exclusive use of processed foods</u>

The high proportion of processed and stored foods in the space diet may require the assessment of potential effects due to accumulation of breakdown products which may result from reactions in processing and long term storage. Thus, an understanding of requirements and tolerances is required for monitoring and controlling the quantity of trace metals, nutrients and accumulation of breakdown products in the diet.

The possibility of reclaiming water and regenerating some of the foods or ingredients, and the use of resources from non-conventional substrates will require development of detoxification procedures. Another aspect to be considered is the hazard involved in creating a new and/or different microflora enhanced by the high proportion of dehydrated foods in the diet. This problem may require the development of new microbiological standards and tests for establishing the bacteriological requirements of dehydrated foods for space resupply.

Other toxicology and pollution control problems are related to the recycling of food or certain portions causing accumulation of volatiles, toxic chemicals, waste materials and other potentially toxic substances. The recycling aspects of any and all chemical additives will have to be studied before a decision is made on their use, even for those chemicals which are used safely on earth.

6. Planning the food supply system

Need for diversity of the diet will require a variety of food sources and food processes. Conventional food processing technology has been developed under earth conditions. Special space conditions (i.e., pseudogravity, atmospheric composition and Coriolis force) may affect some processes. Research on specific problems necessary to predict, anticipate and minimize the adaptation of the existing knowledge is required.

Some of the research and development topics for food technology in space are as follows:

a) Flexibility and versatility

b) Small scale of operations

c) Adaption to habitat conditions

 1) Lack of chemical and noise pollution

 2) Reduced atmospheric pressure operation

 3) Different "gravity" conditions

 4) Utilization of solar energy and "hard vacuum"

 5) Provision for "total recycling"

d) Adaptation to "remoteness" from earth industries

 1) Maintenance and replacement of parts

 2) Fail-safe operations

 3) Simplicity

 4) Minimize utilization of chemicals

e) Provide capability for modifications:
Provide for "the unexpected"

7. Food service

Efficient operation of the total food supply system is achieved by matching of all the food chain components (food processing, size, packaging, preparation, serving and waste disposal). The possibility of using "fast service foods" either in a cafeteria or vending machines as opposed to "home cooking" has to be considered very carefully not only in terms of efficiency, but also in its psychological aspects.

Different scenarios of the food services may lead to different food chain systems and layouts which must be carefully planned.

Diet modifications, methods of processing and feeding have important impact on optimal food service planning (storage capacity, heating equipment, rehydration equipment, dispensing and maintenance equipment). The size of the adequate equipment is still to be determined. The size and qualifications of the staff responsible for the food chain services is another aspect which has to be considered. The possibility of cooking either a prepared or partially prepared meal, requires that all the food supply will be based on "earth-like" concept, but a central meal supply may be an alternate concept. It is essential that these aspects of food preparation for space supply systems should be tested before final designs are chosen.

Table II-1

Summary of Stability Data for Various Dehydrated Products

## Legend of Abbreviations

| | |
|---|---|
| AD | air drying |
| CO | carbon dioxide |
| DD | drum drying |
| FD | freeze drying |
| FMD | foam-mat drying |
| FSD | foam-spray drying |
| H | hydrogen |
| IPD | in-package desiccant |
| MFB | moisture-free basis |
| m | moisture content |
| N | nitrogen |
| O | oxygen |
| NFDM | nonfat dry milk |
| RH | relative humidity |
| SD | spray drying |
| Sun D | sun drying |
| V | vacuum |
| VD | vacuum drying |
| VFD | vacuum-foam drying |
| VPD | vacuum-puff drying |

Table II-1

1. Fruit & Vegetable Powders

| Commodity | Longest Life Observed (Months) | Comments |
|---|---|---|
| Apple | 12-18 | SD, 73°F, 2.8% m, air, 60% NFDM, (MFB) |
| | >8.7 | EPD, 0-73°F, 1.4% m, N |
| | ∿ 12 | VD, 73°F, 2.9% m, N /V/air, IPD |
| | 6-12 | SD, 73°F, 3.8% m, air, 30% NFDM (MFB) |
| Banana | 12-18 | SD, 73°F, 2.8% m, air, 60% NFDM (MFB) |
| | >1.5 | SD, 68°F, 40% RH, air, 4-20% isoelectric soybean protein (MFB) |
| Blueberry | 4-6 | SD, 73°F, 1.7-2.0% m, air, 50-60% NFDM |
| Broccoli | 4-6 | SD, 73°F, 4.5% m, air, 25% NFDM (MFB) |
| Cantaloupe | 4-6 | SD, 73°F, 2.1% m, air, 50% NFDM (MFB) |
| Carrot | 0.5-1 | SD, 73°F, 4.5% m, air, 50% NFDM (MFB) |
| | ∿ 6 | DD, 70-114°F, air, 2.5% rice flour + 0.05% $Na_2S_2O_5$ |
| Cauliflower | 6-12 | SD, 73°F, 5.1% m, air, 67% NFDM (MFB) |
| Celery | 6-12 | SD, 73°F, 3.4% m, air, 30% NFDM (MFB) |
| Cherry | 1.5-2 | SD, 73°F, 6.0% m, air, 50% NFDM (MFB) |
| Cranberry | 1.5-2 | SD, 73°F, 3.7% m, air, 50% NFDM (MFB) |
| | > 14 | DD, <90°F, <4%, air |
| Grape Juice | ∿ 12 | VD, 73°F, 2.5% m, N /V/air, IPD |
| | > 9 | SD, 73°F, 2,5% m, air, 60% NFDM (MFB) |
| Grape (Thompson) | 4-6 | SD, 73°F, 2.7% m, air, 60% NFDM (MFB) |
| Grapefruit | 9 | FMD, 70°F, 10% m, N , Methylcellulose & soya albumin added. Drying temperature 160°F. |

Table II-1 (continued)

| Commodity | Longest Life Observed (Months) | Comments |
|---|---|---|
| Green bean | > 5 | SD, 73°F, 3.7% m, air, 40% NFDM (MFB) |
| Guava | > 6 | FD, 73°F, 0.51-0.73% m, N , pasteurized |
| Lemon | > 4 | FD, 39°F, 0-0.22% RH, N |
| Lemonade | > 3 | PD, 8°F, 1.7% m, V |
| Lima bean | 10.8 | DD, 72°F, 4% m, N , 3 ppm BHT |
| Mango | 4 | FD, 99°F, 1.0-1.5% m, N , 15° Brix |
| Navy bean | ∿ 1 | DD, 99°F, 4% m, N |
| Olallieberry | 4-6 | SD, 73°F, 5.3% m, air, 60% NFDM (MFB) |
| Onion | ∿ 6 | , 59°F, 4-5% m, air, no anticaking agents |
| | ∿12 | , 95-99°F, 6.7% m, air, 2% calcium stearate, onions commercially dehydrated and ground. |
| Orange | 6-12 | SD, 73°F, 2.2% m, air, 55% NFDM (MFB) |
| | 10 | FMD, 70°F, , N |
| | 3 | PD, 70°F, 0.5-1.0% m, V |
| | ∿12 | VD, 70°F, 3.0% m, V, IPD, orange oil |
| | > 6 | FD, 73°F, 1.16% m, N, 13% total soluble solids |
| Pea bean | >12 | DD, 73°F, 4-5% m, air |
| Pea, sweet | 12-18 | SD, 73°F, 2.8% m, air |
| Peach | 6-8 | SD, 73°F, 2.8% m, air, 70% NFDM (MFB) |
| Pineapple | >12 | VD, 70°F, 1.2-2.4% m, air, IPD |
| | 4 | FD, 99°F, 1-1.5% m, 15° Brix |

Table II-1 (continued)

| Commodity | Longest Life Observed (Months | Comments |
|---|---|---|
| Pinto bean | 10.5 | DD, 50°F, 6.2% m, N |
| Pumpkin | 9 | SD, 73°F, 2.9% m, N , 50% NFDM (MFB) |
| Raspberry | 6-12 | SD, 73°F, 3.8% m, air, 60% NFDM (MFB) |
| Rhubarb | 4-6 | SD, 73°F, 4.0% m, air, 60% NFDM (MFB) |
| Spinach | 4-6 | SD, 73°F, 4.0% m, air, 60% NFDM (MFB) |
| Strawberry | 4-6 | SD, 73°F, 2.7% m, air, 65% NFDM (MFB) |
| Sweet corn | 12-18 | SD, 73°F, 2.9% m, air, 25% NFDM (MFB) |
| Tomato | 11 | SD, 73°F, 5.6% m, N , 70% NFDM (MFB) |
| | 6-8 | FMD, 68°F, 1.2-1.5% m, N , IPD |
| | 6 | VD, 70°F, 2.7-2.9%, N , IPD |
| | 12 | SD, 70°F, 1.8% m, N , IPD, $SO_2$ |

Table II-1 (continued)

2. Fruits

| Commodity | Longest Life Observed (Months) | Comments |
|---|---|---|
| Apple | >18 | FD, 72°F, 0% RH, V |
| Apricots | ∿3.25 | SD, 90°F, 12% m, air, apricot sheets 0.3% $SO_2$ |
| Avocados | 12 | FD, 40°F, 2% m, N or V |
| Bananas | >12 | FD, 68°F, 2% m, V, quick freezing |
| | >12 | AD, 55°F, 17.5% m, air |
| | >12 | FD, 55°F, 3.6% m, air |
| | >12 | DD, 55°F, 2.7% m, air |
| Mangoes | >12 | FD, 68°F, , V, fast freezing |
| Peaches | 18 | Sun D, 70°F, 61% RH, N |
| | > 4 | FD, 77°F, , V, osmotically treated |
| | > 6 | FD, 82°F, 10% m, air, blanched |
| | 6 | FD, 100°F, 1.5% m, H-N-catalyst |
| Pears | < 3 | FD 40°F, , V |
| Pineapple | < 3 | FD, 40°F, , V |
| Prunes | 3 | FD, 70°F, , V |
| Raisins | ∿20 | Sun D, 70°F, 16.08%, air, regular variety |
| | ∿8.5 | AD, 70°F, 16.1-16.5% m, air |

Table II-1 (continued)

3. Vegetables

| Commodity | Longest Life Observed (Months) | Comments |
|---|---|---|
| Beets | > 12 | AD, 75°F, 3.7% m, CO or N |
| Cabbage | > 22 | AD, 75°F, 1.2% m, N, 930 ppm $SO_2$, IPD |
| Carrots | 12 | FD, 100°F, 1.5% m, H-N-catalyst |
| | > 21 | AD, 75°F, 5.0% m, N, 660 ppm $SO_2$, IPD |
| Cauliflower | < 1 | AD, 77°F, air |
| Green beans | 12 | FD, 100°F, 1.5% m, H-N-catalyst |
| | > 6 | AD, 75°F, 5-6% m, , variety ideal |
| | > 8 | AD, 77°F, , air, sliced |
| Kale (curly) | < 8 | AD, 77°F, , air |
| Leek | 6 | AD, 77°F, , air |
| Mushrooms | > 7 | AD, 73°F, 6.5% m, air drying T: 110°F |
| Onions | > 22 | AD, 75°F, 2.7% m, N, IPD |
| Peas | 12 | FD, 100°F, 1.5% m, H-N-catalyst |
| Potatoes | > 21 | AD, 75°F, 4.8% m, N, 400 ppm $SO_2$, IPD |
| | 12 | FD, 100°F, 1.5% m, H-N-catalyst |
| | > 12 | IP, 73°F, 3-4% m, N |
| | > 26 | DD, 40°F, 4% m, N + 5 ppm BHA |
| Rutabagas | > 12 | AD, 75°F, 3.8% m, N or CO |
| Spinach | 12 | FD, 100°F, 1.5% m, H-N-catalyst |
| Sweet Potatoes | > 19 | AD, 100°F, 2.9% m, N, IPD |
| Tomatoes | > 12 | DD, 75-80°F, 1.6% m, CO |
| Turnip | 7 | AD, 77°F, , air |
| Yam | > 3 | DD, 70°F, 3.5% m, air |

Table II-1 (continued)

4. Prepared Foods

| Commodity | Longest Life Observed (Months) | Comments |
|---|---|---|
| **Meat & Meat Substitutes** | | |
| Bacon with applesauce | 6 | FD, 70°F, , V |
| Beef hash | > 6 | FD, 70°F, , V |
| Beef pot roast | 6 | FD, 70°F, , V |
| Beef stew | > 6 | FD, 100°F, 1-2% m, V |
| Beef with gravy | > 6 | FD, 70°F, , V |
| Beef with rice | 6 | FD, 70°F, 1-2% m, V |
| Beef with vegetables | 3 | FD, 70°F, , V |
| Chicken and rice | > 6 | FD, 100°F, 1-2% m, V |
| Chicken stew | > 6 | FD, 100°F, 1-2% m, V |
| Chicken with gravy | > 6 | FD, 70°F, , V |
| Chicken with vegetables | > 6 | FD, 70°F, , V |
| Chili con carne | > 6 | FD, 100°F, 1-2% m, V |
| Fish creole | < 3 | FD, 70°F, , V |
| Meat balls with gravy | > 6 | FD, 70°F, , V |
| Meat food product | ~ 6 | FD, 70°F, , V |
| Noodles with meat sauce | < 3 | FD, 70°F, , V |
| Pork sausage patties | ~ 9 | FD, 100°F, , N (Kena, & NaCl & wheat) |
| Pork with potatoes | > 6 | FD, 100°F, 1-2% m, V |
| Scrambled eggs | > 6 | FD, 70°F, , V |
| Spaghetti with meat sauce | 6 | FD, 100°F, 1-2% m, V |

Table II-1 (continued)

| Commodity | Longest Life Observed (Months) | Comments |
| --- | --- | --- |
| Spaghetti with tomato sauce | 3 | FD, 70°F, , V |
| Swiss steak | > 6 | FD, 70°F, , V |
| Turkey with gravy | > 6 | FD, 70°F, , V |
| Veal/barbecue sauce | < 3 | FD, 70°F, , V |
| <u>Soups</u> | | |
| Beef rice | 3 | FD, 100°F, , V |
| Chicken noodle | < 3 | FD, 100°F, , V |
| Chicken rice | > 3 | FD, 100°F, , V |
| Cream of mushroom | < 3 | FD, 100°F, , V |
| Pea soup | < 3 | FD, 100°F, , V |
| Tomato | < 3 | FD, 100°F, , V |
| Vegetable | 1 | FD, 100°F, , V |
| Vegetable | < 1 | AD, 100°F, , N |
| <u>Vegetables</u> | | |
| Carrots with cream sauce | < 3 | FD, 70°F, , V |
| Cream style corn | < 6 | FD, 70°F, , V |
| Green beans with cream sauce | 0 | FD, , V |
| Potatoes (diced) with gravy | > 6 | FD, 100°F, , V |
| Potatoes with parsley | < 3 | FD, 100°F, , V |
| Potatoes (diced) | < 3 | FD, 100°F, , V |
| Potatoes (mashed) | > 6 | FD, 100°F, , V |

Table II-1 (continued)

5. Meat, Poultry, and Fish

| Commodity | Longest Life Observed (Months) | Comments |
|---|---|---|
| Meat and Meat Products | | |
| Beef | > 6 | FD, 100°F, 2% m, H-N-catalyst |
| | ∿12 | FD, 86°F, 1-1.5% m, H-N-catalyst No exposure before packaging, low fat content (i.e., 1.6%), head space $O_2$ <0.2% |
| | ∿10 | VD, 68°F, 2.5% m, air or N, surface fat removed |
| Veal | > 6 | FD, 70°F, 2.0% m,N |
| Lamb | > 6 | FD, 70°F, 2.0% m, N |
| | >30 | AD, 77°F, 5.25% m, N (N + 1.4% O ) |
| Pork | 8 | FD, 100°F, 2.0% m, H-N-catalyst |
| Ham | 5 | FD, 70°F, 3-5% m, V |
| Poultry | | |
| Chicken (white meat) | 12 | FD, 100°F, 2% m, H-N-catalyst |
| Chicken (dark meat) | 12 | FD, 100°F, 2% m, H-N-catalyst |
| Turkey | 6 | FD, 100°F, 2% m, N |
| Fish | | |
| Mackerel | ∿ 2 | SD, 78°F, 42% m, air |
| Oysters | > 2 | FD, 70°F, 2% m, N |
| Salmon | > 6 | FD, 70°F, 2% m, N |
| Tuna | > 6 | FD, 70°F, 2% m, N |
| Shrimp | > 6 | FD, 70°F, 2% m, N |

Table II-1 (continued)

7. Milk and Eggs

| Comodity | Longest Life Observed (Months) | Comments |
|---|---|---|
| Milk, whole | > 20-28 | SD, 63°F, 2.2%m, H-N-catalyst |
| | > 6 | FSD, 80°F, ,H-N-catalyst dried with ozone-free air, deodorized fat |
| | 36 | , 70°F, 2.3%m, V |
| | ~ 6 | VFD, 81°F, , H-N-catalyst |
| Milk, skimmed | > 20-30 | SD, 63°F, 2.4%m, H-N-catalyst |
| | 36-48 | , 70°F, 2.9%m, V |
| | ~ 6 | VFD, 81°F, H-N-catalyst |
| Eggs, whole | > 24 | SD, 70°F, 2%m, N glucose free |
| | 8 | FD, 68°F, 2%m, A |
| Egg, mix | > 6 | SD, 100°F, 2.5%m, V whole egg, skimmed milk, corn oil, and water |

Table II-2*

Products Meeting Six Months Storage Requirement At 100°F

| Product | Highest moisture content reported (%) | storage atmosphere |
|---|---|---|
| <u>Powders</u> | | |
| Apple | 2.9% | air or N |
| Cranberry | 3.4 | air |
| Grape | 2.3 | air |
| Grapefruit | - | V |
| Lima bean | 4.0 | N |
| Onion | 6-7 | air |
| Orange | 3.1 | V |
| Orange-Grapefruit | - | V |
| Tomato | 1.8 | CO |
| <u>Fruit pieces</u> | | |
| Apple | - | air |
| Apricot | 1.5 | H - N |
| Banana | 3.6 | air |
| Peaches | 1.5 | H - N |
| <u>Vegetables</u> | | |
| Beets | 3.7 | CO |
| Cabbage | 0.7 | N |
| Carrots | 1.5 | H - N |

*Legend of abbreviations is attached to Table II-1

Table II-2 (continued)

| Product | Highest moisture content reported (%) | Storage atmosphere |
|---|---|---|
| Green beans | 1.5 | H - N |
| Onions | 2.7 | N |
| Peas | 1.5 | H - N |
| Potatoes | 4.8 | N, H - N |
| Rutabaga | 3.8 | N |
| Spinach | 1.5 | H - N |
| Sweet potatoes | 2.9 | N |
| Tomatoes | 1.6 | N |
| <u>Prepared foods</u> | | |
| Meat and meat substitutes: | | |
| Beef hash | | V |
| Beef pot roast | | V |
| Beef stew | 1-2 | V |
| Beef with gravy | | V |
| Beef with rice | 1-2 | V |
| Chicken with rice | 1-2 | V |
| Chicken stew | 1-2 | V |
| Chicken with gravy | | V |
| Chicken with vegetables | | V |
| Chili con carne | 1-2 | V |
| Meatballs with gravy | | V |
| Pork sausage patties | | V |
| Pork with potatoes | 1-2 | V |

Table II-2 (continued)

| Product | Highest moisture content reported (%) | Storage atmosphere |
|---|---|---|
| Scrambled eggs | . | V |
| Spaghetti with meat sauce | 1-2 | V |
| Swiss steak | | V |
| Turkey with gravy | | V |
| soups: | | |
| none | | |
| vegetables: | | |
| Cream style corn | | V |
| Potatoes with gravy | | V |
| Potatoes, mashed | | V |
| <u>Meats</u> | | |
| Beef | 2.8 | N, H - N |
| Beef, veal | 2.0 | N |
| Lamb | 2.0 | N |
| Pork | 2.0 | H - N |
| <u>Poultry</u> | | |
| Chicken (white meat) | 2.0 | H - N |
| Chicken (dark meat) | 2.0 | H - N |
| Turkey | 2.0 | N |
| <u>Fish</u> | | |
| Salmon, steaks | 2.0 | N |

Table II-2 (continued)

| Product | Highest moisture content reported (%) | Storage atmosphere |
|---|---|---|
| Tuna, steaks | 2.0 | N |
| Shrimp | 2.0 | N |
| <u>Eggs</u> | | |
| Whole egg | 2.0 | N |
| Egg mix | 2.0 | V |
| <u>Milk</u> | | |
| Milk, whole | 2.2 | H - N |
| Milk, skimmed | 2.4 | H - N |

Table II-3*

Products Meeting Two Years Storage Requirement At 70°F

| Product | Highest moisture content reported (%) | Storage atmosphere |
|---|---|---|
| Vegetables | | |
| Cabbage | 2.4 | N |
| Carrots | 5.1 | N |
| Potatoes | 7.1 | N |
| Milk | | |
| Milk, whole | 2.9 | V |
| Milk, skimmed | 2.9 | V |

*Legend of abbreviations is attached to Table II-1

# III. Detailed Report

## A. Stability of Dehydrated Foods

### 1. General Considerations

We have conducted an extensive survey of literature with respect to stability of dehydrated foods. This survey was evaluated with respect to present knowledge about which foods could be stored for prolonged periods of time, and also with respect to a listing of research needs which exist because of gaps in the present knowledge about stability of such foods. The complete listing, in tabular form, of the stability data found in literature is presented in the Appendix. This data was also used for a compilation of a list presenting foods which are known to be stable for 6 months at a temperature of 100°F, and for two years at a temperature of 70°F. These conditions have been used by the U.S. Army in evaluating storage stability of military rations, and is probably as good a guideline for storage stability of resuppplied space foods as any other criterion. Tables presenting the above information are presented in section II of the present report as Tables II-2 and II-3.

In addition, the Summary Report (Section II, Table II-1) presents a summary of the data presented in detail in the Appendices.

An evaluation of research needs with respect to specific dehydrated ration components is presented in section II.B.1.

It may be useful at this point to further discuss some of the major factors affecting storage stability of dehydrated foods, because these factors contribute to the existing uncertainty about storage stability of certain items, and because these factors

will have to be considered in the research program to close the existing gaps. Factors which affect the type and extent of deterioration in dehydrated foods include oxygen concentration, moisture content, temperature, exposure to light and time of storage. The relative importance of each of these parameters vary from commodity to commodity. For instance, freeze-dried beef, chicken and carrots have been found to be very sensitive to the presence of oxygen especially when stored at elevated temperatures.

2. Effects of Oxygen

Studies indicate that elimination of oxygen by packaging in an inert atmosphere would certainly contribute to extending the storage stability of many products. The standard procedure involves repeated cycles of package evacuation, followed by flushing with nitrogen, and sealing of packages in a nitrogen filled chamber. As much as 2-5% of the package headspace may still be oxygen, a sufficient amount to promote oxidation. In the particular case of spray-dried powders, for instance, an inert atmosphere in the package does not seem to result in outstanding improvement of storage life. However, this effect may be due to the fact that a large surface area is exposed to air during processing and that some entrapment of oxygen occurs in the final product.

Excellent retention of fresh flavor quality in dehydrated foods of plant and animal origin has been achieved by Bishov et al., (1971) in "zero" oxygen headspace, using an atmosphere

of 5% hydrogen in nitrogen with a palladium catalyst in which residual oxygen quickly falls below 0.001%. Products stored in "zero" oxygen have been found to be of superior quality to products stored in 2% oxygen. In oxygen-sensitive products such as carrots and sweet potatoes, loss of quality has been observed in packages with a headspace containing as little as 0.5% oxygen within one month at 100°F.

Freeze-dried products are generally the most desirable for space food. Higher flavor retention combined with better texture, faster rates of reconstitution and superior retention of nutrients are some of the characteristics of these products. However, freeze-dried products are also very sensitive to oxygen because of their highly porous structure, as compared to air-dried foods which have a more compact structure created by shrinkage. Oxygen sensitive products to be used as ingredients or to be subdivided into smaller portions for individual consumption, must be prevented from repeated exposure to air in assembly lines and may require a complete repetition of the deaeration procedure after each operation. This may result in higher cost and possibly lower quality. In meats for instance, exposure of the freeze-dried meat to air before packaging under nitrogen, shortens the storage life, particularly of meat with a high fat content. Evidence has been found that freeze-dried beef absorbs oxygen, which may be desorbed during subsequent storage.

From the results reported in the literature we can extrapolate that a complete absence of air during storage combined with a minimum exposure to air during processing will result in a marked improvement of shelf life.

The above facts are particularly significant to storage in a space habitat because it is conceptually possible to achieve a storage environment with an essentially absolute absence of oxygen by allowing the food to be exposed through an appropriate system of locks to the space environment. Since the food is essentially anhydrous it is probable that the exposure to the very high vacuum of space will not result in substantial losses of flavor through volatilization, and it is possible that undesirable textural changes due to excessive dehydration will be avoided.

3. Effects of Moisture on Storage Life

Moisture content is another very important parameter in the stability of dehydrated foods (Tannenbaum, 1976; Karel, 1975). It has been suggested that the optimal amount of water for long term storage corresponds to the B.E.T. monolayer value (Salwin, 1963). Rauch (1963) on the other hand has reported that items such as freeze-dried spinach, orange juice, cabbage and cottage cheese are more stable at a zero moisture content and that items such as precooked and raw pork and chicken, potatoes and corn have maximum stability at the monomolecular moisture content. Army requirements specify that freeze-dehydrated foods should contain a maximum of 2% moisture.

Freeze-drying of beef, sweet potatoes and spinach to a moisture content of 1.2% has been found to be detrimental to these foods and therefore, is inadvisable to store these foods at very low moisture levels. It appears that optimal moisture contents can not be predicted with precision on the basis of theoretical considerations.

4. Effects of Storage Temperature

Storage stability of dehydrated foods bears in general an inverse relationship to storage temperature. Temperature affects not only the rate at which a deleterious reaction takes place but also the kind of spoilage mechanism prevailing in the food. Activation energies for a series of reactions that take place in foods are presented below:

| | | |
|---|---|---|
| enzyme reactions | 10-15 | Kcal/mole |
| hydrolysis | 15 | " |
| lipid oxidation | 10-25 | " |
| nonenzymatic browning | 25-50 | " |
| protein denaturation | 80-120 | " |

Activation energies may be dependent on moisture content and comparison of stability at several temperatures must be based on products with comparable moisture levels.

5. Effects of Light

Adequate packaging for dehydrated foods needs to be provided to protect them from light. Some deteriorative reactions in dehydrated foods are initiated or accelerated by light. These include oxidative rancidity of fats and oils and destruction of vitamins such as riboflavin, ascorbic acid and thiamine. Riboflavin in particular is especially photosensitive and upon exposure to light not only loses its vitamin activity but also sensitizes other components to photodegradation. Food pigments such as chlorophyll will rapidly fade in the presence of light.

Although wavelengths below the range of 450 to 500 nm have

the greatest catalytic effect on foods, longer wavelengths may also have some undesirable effects (Karel, 1960).

6. Retention of Flavor

The limiting characteristic for most dehydrated products is loss of desirable flavor. Some flavor compounds are lost in dehydration. Additional losses may occur during storage. Flavor retention needs to be carefully considered in those products in which the principal flavor constituents are volatile oils as in onions. Products that contain volatile and nonvolatile flavors as in the case of most root vegetables (e.g. carrots and turnips), volatile retention is not as critical. Flavor defects in dehydrated products are however, not solely due to volatile losses. Chemical reactions and in particular oxidation and nonenzymatic browning, greatly contribute to flavor deterioration. A large selection of dehydrated products have been obtained with adequate flavor characteristics. Flavor characteristics are dependent on the methods of drying, pretreatment, handling and storage conditions.

Freeze-dried products present in general better organoleptic characteristics as compared to other dehydrated products upon processing. However, freeze-dried products present the problem of being more demanding in regard to their packaging requirements. Good flavor characteristics upon processing will quickly deteriorate if adequate handling is not provided. The most important factors to be considered are the hygroscopicity of the material and the large surface area exposed due to the high porosity of the material. As in the case of most dehydrated foods, flavor is the limiting characteristic in prepared foods. Prepared foods present the advantage that

their flavor characteristics can be modified by formulation. Spices for instance, could contribute not only to enhance flavor but to retard oxidation in some cases. Antioxidant properties have been observed in some spices (Tuomy et al., 1969). A product that has been studied extensively is dehydrated milk, and flavor loss was found to limit shelf life. Flavor defects in whole milk can be associated with the fat phase and with lactose-protein interactions. Flavors such as fruity, coconut, stale-fat, waxy, oxidized, tallowy. oily, metallic, cardboard, etc. are changes associated with the fat-phase. Off-flavors developed as a result of lactose-protein interactions have been generally described as cereal, malty, stale, burnt-feathers, etc. Good flavor stability has been obtained when the exposure of the product to oxygen is minimized. Handling, drying and packaging the concentrate and powder in an inert atmosphere will result in a high quality product. The use of oxygen scavengers such as a palladium catalyst in an atmosphere of 5-10% hydrogen in nitrogen has resulted in a marked improvement of the product's shelf life. Use of antioxidants such as propyl gallate and lauryl gallate added to the powder at the 0.01% level also contributes to extend storage life.

7. Color Characteristics

With respect to color changes, significant losses of carotenoid pigments in spray-dried fruit powders such as orange juice powder occur during the conditioning period. 18-27%

losses of carotenoid pigments have been observed in dehydrated orange juice conditioned at 70°F for 75 days. This conditioning period is absolutely essential in achieving good storage stability of elevated temperatures through the use of in-package desiccation.

Green pigmented plant products will retain their color if adequately protected from light. Color intensity decreases in products such as carrot, pumpkin and tomato when exposed to storage conditions that would favor oxidative deterioration of carotenoids. Some products like corn are more resistant to color changes. Products such as spinach and broccoli would show less changes as due to masking of chlorophyll combined with the possible presence of antioxidants.

The pink color of freeze-dried meats is lost during storage in nitrogen as well as in air, due to irreversible changes in haem pigments and browning deterioration. On storage above freezing temperatures the pink color gradually changes to light gray-brown. As storage proceeds, brown, yellow-brown and orange-brown colors develop. On storage, the astacene pigment of shrimp will fade in the presence of oxygen. Since the pigment is located on the surface, even small amounts of oxygen present in the container will result in fading of the product (Lusk et al., 1964).

Browning due to amino-carbonyl and carbonyl-carbonyl interactions, known as "non-enzymic browning" is a major deteriorative mechanism in dry foods and is sensitive to increases in water content. Control is best achieved by regulating water activity and addition of additives such as sulfite.

8. Rehydration and Texture

It has been found that the greater the degree of drying, the slower and less complete the degree of rehydration. Rehydratability is determined by the extent of cell structure damage, which is affected also by factors such as pretreatments and storage conditions. Many of the commercially dehydrated vegetables, for instance, exhibit a dense structure with most of the interior capillaries collapsed, or greatly shrunken. This kind of structure does not rehydrate well and therefore, will affect the textural quality of the final product. Freeze-drying and vacuum puffing have alleviated some of the problems related to rehydration. Pretreatments such as blanching, freezing and the aid of additives such as sugars, salts and glycerol have also contributed to improve reconstitution.

Fruit and vegetable powders high in fiber (i.e. asparagus, celery, broccoli) do not seem to show any problems as far as reconstitution is concerned. Fruit powders with high sugar contents present more difficulty in reconstitution and therefore, new formulations and processing need to be investigated to obtain readily reconstitutable powders.

Animal tissues present in general a decrease in the water holding capacity. For instance, freeze-dried fish and shrimp, immediately after freeze-drying reabsorb water completely. However, a large amount of this water can be easily squeezed out by applying a slight pressure. Shrimp would lose approximately 33% of this water of hydration

(Matsuda, 1969; Moorjani and Dani, 1968). Freshly prepared freeze-dried meat rehydrates to a maximum level of 80-100% of its original water content. The extent of rehydration, however, is greatly affected by storage deterioration.

A characteristic that has not been satisfactorily studied in many cases or not very accurately evaluated is texture. Overall results presented in the literature seem to point out that texture of a successfully dehydrated food would be one of the last characteristics or functional properties to fail upon storage. There are however, exceptions to this general pattern.

In dehydrated fruit, texture is often the decisive quality criterion. It is very important that dehydrated fruit regains its turgid texture upon rehydration. Most dehydrated fruit however, becomes mushy when rehydrated. Some attempts have been made to improve the firmness of products such as red tart cherries and apples by chemical pretreatment with calcium chloride. It should be noted that dried fruits have been utilized mainly in bakery products, in "cooked" sauces or as snacks in their dehydrated form. However, if the final goal is to obtain a product which upon rehydration closely resembles fresh fruit a great deal of work is still required.

Research is needed in the area of dehydration of crisp products such as celery, tomatoes and lettuce which are unable to withstand dehydration and which upon reconstitution turn into unacceptable mushy products. Leafy products in general, are severely affected in their textural characteristics

as a consequence of dehydration and even products such as spinach suffer a definite decrease in acceptance regardless of variety. Improvements in the preparation of vegetables prior to drying (i.e. chemical pretreatment) as well as a careful selection of process conditions are mandatory to obtain better products.

Selection of varieties most suitable for dehydration is essential. Factors such as flavor, color, pungency, and sugar content need to be carefully considered. A high solids content is perhaps the most important requirement. Freeze-dried vegetables such as green beans, peas, corn, carrots, etc. have been processed having good texture characteristics. Upon storage texture of air-dried vegetables will deteriorate if the product is exposed to high temperatures or if inadequately dehydrated. Water contents over 10% will result in a series of chemical changes affecting the physical characteristics of the product. Water contents under 2% for instance, would most likely result in problems at the rehydration stage.

Although flavor and appearance of freeze-dried meats that have been rehydrated and cooked are the same as for frozen meats, texture is different and certainly the main problem associated with dehydrated meats. Dryness and toughness are still problems that require further investigation. Meat products in which meat is in the form of small pieces, e.g. ground beef, rehydration and end-product texture do not present a problem. Another difficulty associated with dehydrated beef is that the textural quality of meat shows a significant variation from lot to lot, being tender in some cases and extremely tough

in others. Textural characteristics of dehydrated meats are greatly affected by storage conditions. An increase in temperature as well as exposure to $a_w$ over 0.25 will result in a definite increase in hardness and chewiness in cooked freeze-dried beef (Heldman et al., 1973). Texture deterioration can range from the turgidity characteristic of fresh meat at conditions such as 1.7% moisture and 0°F storage, to a dry cellulose-sponge-like texture in samples stored at higher temperatures (90°F) within a 5-month period (Thomson et al., 1962). Pork, poultry and fish present similar textural problems.

Additional work will be required in regard to texture of dehydrated meats and fish. Main areas of investigation involve: a) prediction of the final characteristics of the dehydrated product based on appropriate instrumental analysis of the raw material, b) improvement of the water holding capacity of meats by pretreatment and/or modification of actual conditions used for drying processes and, c) determination of exact final moisture content in the product that would be required to obtain optimum stability including rehydration characteristics

9. Nutritional Value

Many parameters influence the retention of nutrients. In the case of fruits and vegetables for instance, parameters such as post-harvesting time, variety, pretreatment (blanching, freezing, sulfiting, etc), kind of nutrient, type of drying and the actual conditions at which the drying is carried out determine the nutritional quality of a given product. In storage moisture content, package atmosphere, temperature and time are the most important parameters. Optimum storage conditions vary from commodity to commodity. Most dehydrated fruits and fruit products require very low levels of moisture for nutrient retention. Mylne and Seamans (1954) observed that only 10% of the ascorbic acid in orange juice powder is lost after 6 months of storage at severe conditions such as 100°F if adequate desiccation was provided. Samples without in-package desiccation lost up to 75% ascorbic acid within the same period of time. Similar results were reported by Karel and Nickerson (1964) and Draudt and Huang (1966), whose results suggested that moisture content should be reduced to the lowest possible level for prevention of ascorbic acid losses. On the other hand, extremely low levels of moisture result in a reduced nutritional quality in products such as avocados, tomatoes and some vegetables. Very low levels of moisture enhance deteriorative reactions such as lipid oxidation. Losses of fat-soluble vitamins during storage are most likely due to interactions of the vitamins with free radicals or peroxides produced during lipid oxidation.

The exclusion of oxygen, in most cases, seems to favor the stability of nutrients, particularly in products with a large surface area. The absence of oxygen is essential for good quality of oxygen sensitive products like meats, whole milk and carrots. Other nutrient losses are due to non-enzymatic browning (Regier and Tappel, 1956), especially in dehydrated meats.

Factors which contribute to losses in nutritional quality of dehydrated meats are moisture content, temperature, oxygen exposure, pH and time of storage. A complete removal of water does not completely eliminate product deterioration although the rate of deterioration is greatly reduced. Low temperatures, a minimum exposure to oxygen and low pH values favor storage stability of meats.

Provided that storage conditions are adequate dehydrated milk could be kept with its initial protein and vitamin quality intact for several years. Factors that contribute to retention of nutrients include low temperatures and moistures as well as antioxidants and packing in an inert atmosphere.

## B. System for Generation and Utilization of Stability Data

### 1. Introduction

One of the major tasks in planning a food supply is the specification of conditions under which the food will keep its quality for a defined period of time. The quality of foodstuff may be defined in many ways such as: nutrient content, color, flavor retention, texture, lack of detectable off-flavors and many other related quality factors.

The shelf life of a food product is affected by many reactions and parameters that can be categorized as follows:

a) Reactions of components pertinent to the modes of failure of the specific food.

b) History of the product to processing, and changes occurring during processing.

c) Protective properties of the package.

d) Environmental conditions during distribution and storage.

The kinetic approach for predicting nutrient or quality losses in foods has been investigated intensively during the past several years (Saguy et al. 1978):

Prediction of nutrient or quality retention during processing is exemplified by work of Aguilera et al. (1975) Lund (1973) Mulley et al. (1975) and Teixeira et al.( 1969)

Prediction of shelf life during storage is exemplified by work of a number of authors. (Stephens and McLemore, 1969; Cort et al, 1976; Singh and Heldman, 1976; Singh et al., 1975; Quast et al., 1972, Quast and Karel, 1972, 1973; Karel, 1973, 1974, 1975; Herlitze et al., 1973, Herrmann, 1974, Labuza, 1972,

1973, Lee et al., 1977; Wanninger, 1972).

Acceleration of tests for prediction of storage stability of dried foods may be achieved by the following methods:

a) increased temperature

b) acceleration of oxidation

c) tests at elevated moisture contents

d) tests using combined effects

There are two basic approaches for determining the pertinent kinetic model:

1) Experiments in a factorial design at constant levels of the variables where only one variable is changing at a time.

2) Dynamic procedure in which more than one variable is changing during the experiment.

Only limited accelerated test approaches have been reported in the literature. These are reviewed below:

2 Tests at elevated temperatures

This is the most widely used technique. Data are obtained at high temperatures and are extrapolated to the desired temperature. The theoretical justification for this technique is based on the fact that rate of reaction increases exponentially with the absolute temperature (T).

$$k = K_o \exp\,[-E/RT]$$

where $K_o$ is a constant. If the mechanism of deterioration does not change, E is constant. In practice a "so-called" $Q_{10}$ value is often used to express temperature effects.

$$\log\,(Q_{10}) = 2.19\,\frac{E}{(T+10)\ (T)} = \log\left(\frac{t \text{ at } T + 10}{t \text{ at } T}\right)$$

where t is shelf life at the specified temperature, T (°K).

High temperatures do accelerate reactions, but one must use

caution interpreting results, since at high temperature mechanisms of deterioration may change if one reaction is accelerated more than the other. There may also be a problem with physical changes such as melting of fats. The use of high temperatures is however, the easiest way to accelerate shelf-life testing.

A major point which must be resolved in any accelerated testing scheme is the proper choice of quality deterioration index. This index must be the one limiting the shelf life, or be correlated with a limiting deterioration.

The adequacy of the model used has in all cases to be tested either by comparing the variance of different models used by an F- test or by testing the correlation coefficient. Methods for carrying out regression analysis either by linear or non-linear least squares and F-tests are readily available.

Waletzko and Labuza (1976) reported that all models of deterioration (in intermediate moisture foods) deviated from Arrhenius relationship when higher temperature data were projected to lower temperature. This extrapolation under estimates the true shelf-life.

## 3. Accelerated tests for oxidative rancidity

### a. General considerations

Rancidity due to lipid oxidation is a serious problem in some stored foods and is often limiting in dry foods.

The first step in a typical accelerated shelf-life test (ASLT) is to select a suitable method for testing the food product under consideration. Next, a sample is placed under the conditions of the test and the time $t_F$ is measured for reaching a specific end point. This time is defined as the

induction period. The most difficult step is to translate the obtained data into actual product shelf-life of safe storage. The following assumptions are used:

1) The overall rate constant is proportional to the reciprocal of the induction period $t_F$ where $t_F$ is defined as the time to reach a constant percent oxidation of the substrate.
2) The energy of activation remains constant over a wide range of temperatures. This assumption is not always valid, especially when antioxidants and metal catalysts are present.

Changes in the energy of activation may also be affected by concentration of antioxidants, presence of chelating agents, volatility of antioxidants, the number of phases and the solubility and pH in each phase (Scott, 1965; Ingold, 1970; Klaui, 1971; Cornell et al., 1970; Lea, 1960; Ragnarsson and Labuza, 1977).

b. Specific tests used

The following is a short summary of the most used methods (Ragnarsson and Labuza, 1977) involving oxidation and rancidity:

i. The Schaal Oven Test (SOT)

This method was developed in the baking industry in the 1920's. 50g samples are held in 250 ml beakers with watch-glass on the top at about 63°C. The samples are smelled daily until rancidity is detected. Lea (1962) advocated the use of peroxide values to monitor the oxidation and the use of much smaller samples (0.2ml).

For complex foods, a temperature of 60°C is too high. The end-points used (either a rancid odor or a peroxide value of 70-120) are appropriate for correlating with the shelf life at lower temperature.

ii. Oxygen Absorption Methods (OAM)

Many versions of the Oxygen Absorption Method are available. In most commonly used procedures 100 to 1000 mg. samples of lipid are kept in 30 ml flasks connected to mercury manometers. These are connected to a pressure recorder. The sample is kept at atmospheric pressure in oxygen at 100°C. The end-point is taken as the time when a marked drop in pressure occurs. If the sample absorbs oxygen only gradually throughout, the end-point is taken at the organoleptic rancid point. In order to get a sharp end-point with vegetable oil, it may be necessary to replace air with oxygen. The OAM is known as the Modified (Martin, 1961) Sylvester et al., (1942) Method.

Eckey (1946) proposed a somewhat similar design in which 1 g. of lipid was suspended in 12.5 g of "pure silica sand" in a 50 ml flask. The temperature was maintained at 80°C. The end-point was taken as the time for the sample to absorb 3 ml (STP) of oxygen. The author used air as the surrounding atmosphere, but suggested a modified design that could be used with pure oxygen.

The temperature used in these methods is considerably higher than that used in the Schaal Oven Test. This is a serious disadvantage even for simple lipids.

A considerable disadvantage of both methods is that at the relatively low oxygen pressures used (3 and 15 psia in the

Eckey and Sylvester-Martin methods, respectively) the rate can easily become dependent on the oxygen pressure and the rate of oxygen dissolution. The dependence on oxygen increases with increasing unsaturation of the lipid. Sylvester et al. (1942) found that for palm kernel oil the induction period was almost cut in half when air was replaced with pure oxygen. Pohle et al. (1962), using a considerably higher oxygen pressure, found less than a 10% increase in rate as oxygen pressure was increased from 65 to 115 psia. At higher temperatures the dependence was found to be even greater, as expected (Bennett, 1964).

iii. The Active Oxygen Method (AOM)

20 ml samples of lipid are kept in 1 in X 8 in glass tubes, and clean dry air at 2.33 $cm^3$/sec is bubbled through. The temperature is maintained at 97.8°C. Periodically peroxide values are measured, until they reach about 120 meg/kg. Unlike most other ASLT methods, this one has been rigorously standardized.

The main problem with this method is the high temperature used. Generally, an arbitrary multiplying factor is used, based on previous experience, to give an estimate of the shelf-life at room temperature. The method cannot be used with formulated foods.

iv. The ASTM Oxygen Bomb Method (OBM)

This method has long been used in the rubber and petroleum industry. 15-30 g of lipid are added to a glass container which is fitted into the bomb. The oxygen pressure is either 65 or 115 psia and the temperature 99°C. The induction period

is taken as the time to reach a pressure drop of at least 2 psia/h was obtained. Stuckey et al. (1958) modified the method by using a smaller sample which was spread on tissue paper in order to increase the contact between the lipid and the oxygen. For lard a five-to-eight-fold increase in the rate was obtained in this way. Problems with this method, include the high temperature, and contaminants which can be introduced with the tissue paper. Addition of metals can produce acceleration of oxidation.

v. Other Methods

A number of other methods have been suggested for specific applications. The Weight-Gain Technique for instance (Sherwin, 1968) is based on the increase in weight of the lipid as it continues to absorb oxygen.

Because of the problems experienced with the high-temperature ASLT methods, alternative means of acceleration have received more interest recently. Most of these tests use some form of metal-containing pro-oxidants.

Uri (1961) has pointed out that since the temperature coefficients of antioxidant efficiency vary with the nature of the antioxidant, high-temperature ASLT studies are open to criticism, and adding metallic pro-oxidants may be a more meaningful method of acceleration. The author used ferrous phthalocyanine as a catalyst. Berner et al. (1974) used hemin catalyst.

The use of metallic pro-oxidants in ASLT studies, perhaps in conjuction with a moderate temperature elevation, should be given careful consideration. One of the problems involved is

that some foods contain higher levels of endogenous metals than others. Therefore, different amounts must be added to different foods to give the same percent acceleration.

Recently we developed a modified procedure for oxygen uptake in dehydrated foods. The method is as follows:

Dried powder samples are evacuated for a given time (approx. 3 min) and then suspended in de-aerated water in order to release the sorbed and entrapped oxygen. The released oxygen is compressed to a known headspace and the concentration is determined by an oxygen probe.

Results obtained so far indicated that the accuracy of the determination was app. $\pm$ 5-7%. In view of the very low oxygen concentration involved it was suggested that this method may be applicable for determining the rate of deterioration in quite a short time thus providing a rapid and convenient tool.

It is worth emphasizing that this procedure provides the only accelerated method which may be carried out at the normal storage temperature, thus eliminates the problems related to changes of mechanism which may take place at high temperatures.

## 4. Accelerated tests at increased water contents

Storage stability of moisture-sensitive foods can be predicted either by establishing the kinetic model of deterioration or by the "no-model" method (Mizrahi and Karel 1977a,b). In the first approach the kinetic constants are determined for the appropriate model in most cases at constant temperature and different levels of moisture contents. Methods of

prediction of shelf-life of packed stored foods on the basis of laboratory tests on kinetics of deterioration and on mass transfer properties of packaging materials were reviewed recently by Karel (1973, 1975), Herrmann (1974) and Labuza (1972, 1973). In order to overcome the major shortcoming of the available methods due to tedious time consuming experiments the "no-model" approach was used (Mizrahi and Karel 1977a) whereby accelerated test technique was developed for dehydrated products undergoing deterioration due to moisture-sensitive reactions. The method is applied to isothermal storage of dehydrated products packed in water-permeable plastic materials. The method is based on monitoring quality changes in the product which undergoes rapid deterioration because of a high, albeit controlled, rate of moisture gain. The method utilizes the "no-model" approach in which previous knowledge of the reaction mechansim involved is not needed.

Other methods include calculation of moisture transfer between ingredients in dehydrated food mix for predicting stability (Salwin and Salwson, 1959; Hokoji et al., 1965 and Charie et al., 1963).

5. Combined Methods

Combined methods allow changes in more than one variable at a time and in most cases uses dynamic conditions in which temperature and moisture varies at the same time.

Dynamic non-isothermal tests are also used but in this case they require either previous knowledge of the mechanism involved, or certainty that deterioration reactions are functions

of temperature only.

The use of non-isothermal kinetics has grown considerably since it has been first introduced by Rogers (1963). Its impact was mainly on pharmaceutical products (Cole and Leadbeater, 1968; Erikson and Stelmach, 1965; Zoglio et al. 1968; Kay and Simon, 1971; Greiff and Greiff, 1972; Maulding and Zoglio, 1970).

Nonenzymatic browning which is one of the major problems in storage was monitored by accelerated test procedure whereby moisture and temperature of the sample increased simultaneously (Mizrahi et al., 1970a). These tests were made possible by prior knowledge of the kinetic models for the specific system (Mizrahi et al., 1970b). This knowledge was essential in extrapolating the obtained data to conditions of low reaction values.

## C. Engineered Foods

### Introduction

The difficulty in providing a sophisticated and varied food supply for the limited facilities available in the environment of space habitats is obvious. The human desire for variety, organoleptic quality combined with the obvious requirement for safety and nutritional value will however result in demand for varied and sophisticated diets. One of the avenues we feel should be fully explored in this respect is the provision of engineered foods.

In recent years we have demonstrated that engineered fruit analogs based on calcium alginate and designed for inclusion in space diets may be freeze-dehydrated, and form a basis for a controlled nutrient content food of high palatability (Luh et al. 1976). Other engineered foods have potential for supplying various needs of specific population groups (Karel, 1976).

Engineered foods are produced by incorporation of natural and/or synthetic components into systems having desired nutritional, organoleptic and stability characteristics. The development of knowledge about functionality of ingredients provides the basis for development of engineered foods. Since organoleptic properties are by far the most important stimuli for making nutrients into food, development of organoleptic equivalence of engineered foods allows utilization of a variety of nutrient sources no matter what their origin. Furthermore, organoleptic equivalence also permits, for the first time, the

construction of nutrient sources to the specification of human need rather than dependence upon the vagaries of natural products.

In the developed countries and in a number of the more rapidly advancing developing countries, there are certain common societal pressures that lead to these changes in the traditional modes of food production and consumption. These include (1) pressure the reduce labor, (2) concern for environment, (3) concern for nutrition and safety of foods, and (4) concern for availability of resources.

Engineered foods allow the utilization of components to achieve aims which provide answers to some of these problems. Engineered foods provide first of all flexibility. By utilizing a variety of essentially equivalent components for the same purpose, it is possible to bridge periods of shortage of specific raw materials. For instance, the protein present in milk is always the same and obtainable only as secretion from lactating animals. Engineered high protein beverages such as milk analogues could utilize properly processed proteins from oilseeds, grains, yeast, or even milk protein, extracted, processed, and stored during years of plently to provide a reserve for years of shortages.

Engineered foods may also help meet the need for new systems to provide tailored nutrition since they provide a basis for formulation of nutritionally balanced foods for specific population groups. In addition, they may in fact provide a potential for medication through the food supply.

This last concept is controversial, but it is entirely possible that it may represent less of an intrusion on individual liberties than some practices. It may be possible, for instance, to incorporate fluoride or phosphate compounds in cookies or in chewing gum to reduce caries development in children and thus reduce the need to fluoridate water which is consumed in part by older population groups for whom fluoride is less beneficial.

Foods designed for space flights were in fact compounded on the basis of high palatability, therapeutic potential (for instance supplementation with potassium), nutritional balance and maximum stability characteristics. Key potential benefits of engineered foods are shown in Table 1 (Sarrett, 1975).

All of the above considerations will be even more significant in the applications to the diet of the space habitats. Flexibility is an obvious advantage, since it will allow the gradually increasing level of incorporation of space-grown food ingredients into the engineered food system (if at least part of the food preparation is done in the habitat), will allow choice of components particularly to resupply (because of stability, palatability or other considerations) and will allow modularization of the diet which could be invaluable in case of changes in requirements or in supply. Our consultant, Dr. Heidelbaugh, pointed out to us that the availability of engineered foods in the skylab experiment was indispensable to the provision of the controlled diet.

## Present Status

Engineered foods are not new. Bread and other baked items, cheese, margarine, sausages, and many other ancient food concepts fall into the category of engineered foods. Even the more recent concept of utilization of synthetic components and of building in controlled nutritional characteristics is by now a well-established industrial reality.

According to Sarrett (1975), engineered foods which affect human nutritional status fall into four groups as follows: (1) special dietary foods which constitute the entire diet (Table 2). These foods require nutritional "completeness." They include various infant feeding formulas and diets for special uses such as weight control, treatment of metabolic disorders, and diets for metabolic studies; (2) foods which replace entire meals such as meals in school feeding programs; (3) engineered foods which imitate basic foods, e.g. imitation fruit juices or egg substitutes. The nutritional implications of such foods depend on the degree to which nonconventional ingredients are utilized in their manufacture. Fabricated meats constructed from desinewed, deboned meat cuts and from added beef fat have nutritional characteristics similar to conventional meats. Replacement of part of the muscle by textured vegetable oils causes major changes in overall nutrient content. (4) Minor foods which ordinarily provide relatively few calories in the diet such as synthetic caviar, whipped toppings, and low calorie snack foods.

Major Research Needs

The future development of engineered foods will require major research advances in the material science of foods. The chemical industry developed its present state of advanced technology by characterizing the physical and physio-chemical properties of the materials being processed and by designing engineering processes on this basis. In contrast, the food industry has developed on a traditional basis in which skilled artisans relied on qualitative and subjective procedures passed from generation to generation.

Food materials are complex and have many attributes related to organoleptic quality which are difficult to correlate with standard engineering properties. Mechanical properties of foods are only one example of complex properties which determine organoleptic quality, in this case the texture. Research is needed in order to use the measurement and characterization of chemical, physical, and functional properties of food materials in determining the overall quality, processing suitability, and shelf stability of foods. There is also need to research a basis for formation of internal structural morphology to utilize it to produce foods with controlled properties.

There are also nutritional questions requiring investigation. Since engineered foods can produce a significant and profound change in the dietary of a human population group within a very short time period (Miller, 1978a), there is no time for adaptation and selection to provide optimal utilization.

There are thus several nutritional problems of significance. They can be divided into three problem areas: (1) nutritional equivalence, (2) nutritional superiority and (3) nutritional unbalance. In the case of the first area, the problem becomes important when the intake of the analogue becomes a significant part of the total daily intake. In addition, the possible absence of nutrients for which requirements have not been met is also of concern. These include both known and unknown. For example, information is being obtained that suggests an essential role for several trace elements not previously considered important in human metabolism. These include silicon, chromium, boron and others.

Problems associated with development of products of nutritional superiority in relation to natural products can mostly be associated with two questions. First, what indeed represents a more optimal pattern of nutrient? Since 1950, the FAO has been attempting to define, with little success, "optimal" patterns of amino acids. Thus the problem resolves itself in the question of "optimal for what purpose?" since no standards of optimality are available for comparison or judgment. Second is best described as the "Australian rabbit problem", i.e., by modifying a pattern of long standing, are we developing other problems of unknown dimension? Recently, for example, questions have been raised concerning the advisability of changing the fatty acid pattern of infant formulae (Reiser & Sidelman, 1972). This was done to provide a "more

optimal" pattern of fatty acids and thus help protect against coronary artery disease. Now, questions concerning coincident effects on myelin development and cholesterol metabolism need answering. None of these were considered when these changes were made.

Finally, the problem of possible nutritional imbalance must be considered when a food or new composition is introduced, not in terms of interaction within the food but rather as a result of a changing overall dietary pattern.

The problem of toxicology is reasonably straightforward, but a major problem in making such assessment is associated with the lack of knowledge about effects under stress conditions

Siu et al. 1977.

TABLE 1

POTENTIAL BENEFITS OF ENGINEERED FOODS

| |
|---|
| "Complete" infant formulas |
| "Complete" diets for special uses |
| Modify caloric density |
| Specify ingredients and nutrients |
| Improve dietary patterns |
| Offset disadvantages of some foods |
| Better use of protein sources |
| Utilize by-products |
| Eliminate naturally occurring toxicants |
| Convenience foods - good nutrition<br>- save time |
| Uniform quality, palatability, and stability |
| Meet needs of industrialized society |
| Snacks - satiety without calories<br>- nutritionally adequate |
| Supply needs of underdeveloped nations |
| Stretch world food supplies |
| Good nutrition at low cost |

## D. Improvements in dehydration technology

### 1. Introduction

The present study was devoted to evaluation of stability of dehydrated foods, prepared with the currently available technology. However, there exists the potential for substantial improvements in the stability of dehydrated foods through improved processing technology. Improved stability may come about either by producing inherently deterioration-resistant forms of dehydrated food, or by increasing the initial quality so that even after some decrease in this initial state, the food remains acceptable.

Several potential approaches to improved technology of producing and processing dehydrated foods are discussed below.

### 2. Freeze-drying

Freeze-dried products are considered to have the highest quality possible in a dehydrated foodstuff, because their structural rigidity is maintained, thermal damage minimized, and volatile retention is improved. Reviews written by Karel (1973, 1974) and King (1970) summarize the knowledge to date. Among the recent developments are the following:

#### a) Continuous freeze-drying

Continuous and increasingly efficient freeze-drying operations are becoming more common (Havinghorts, 1970; Karel, 1973). This trend is limited, however, to operations handling large volumes of a single type of product, (e.g. coffee). Ration components and other items processed in limited quantities are still dried in batch driers.

b) Approaches to reduced drying time

Decreasing the drying time of the freeze-drying process is an important factor in improving the process efficiency. One approach to more rapid drying is increasing the surface area (Anon, 1972; Kessler, 1975). Ultrafine grinding of frozen liquid to the size of the ice pockets may abolish any diffusion limiting drying steps (King, 1974). Specific freeze-driers have been designed for particular products (Havinghorst, 1970). A second approach is based on improving the heat transfer coefficient, (Karel, 1973). The low air temperature required for preventing melting resulted in long drying times, preclude its wide application. An attractive solution is the use of a fluidized bed in conjunction with atmospheric freeze-drying (Malecki, 1970). The increased air circulation and exposed surface area increases the heat transfer area and coefficient, thus reducing drying time even at low temperatures.

c) Use of desicant

The substitution of a reusable desicant for the presently used refrigerated condensers is a cost-reduced approach suggested by King (1975).

d) Improved volatile retention

Improved volatile retention may be accomplished by combination of the following procedures (Flink, 1978):

1) Liquids are preconcentrated to increase solids concentration.

2) Slush freeze-drying also increases the concentration

3) Prefreezing under pressure has been shown to retard volatile loss (King, 1974).

4) The replacement of water with a low molecular weight solvent in which the volatiles are not soluble and subsequent freeze-dehydration may give up to 100% volatile retention.

e) Microwave freeze-dehydration

Microwave heating has potential for increasing drying rates. The four potential rate-limiting steps, which occur in series in the freeze-drying processes (Ang et al. 1977a) are:

1) External heat transfer from the heat source to the outer surface of each piece of material.

2) Internal heat transfer from the outer surface of each piece to the sublimation front through the dried layer.

3) Internal mass transfer of water vapor from the sublimation front to the outer surface.

4) External mass transfer of water vapor from the sample surface to the condenser or other moisture sink.

Steps 2 and 3 assume increasing importance as the thickness of the dried layer increases during the process.

Delivery of heat directly to the sublimation zone overcomes problems of supplying heat by conduction from the surface of the material being dried, eliminating the need for excessive surface temperatures (Kind, 1970; Karel, 1974).

Very rapid rates of freeze-drying would be possible if microwave energy could be dissipated rapidly enough in the

frozen core so as to achieve high internal mass transfer coefficient from low pressure with maximum allowable water vapor partial pressure driving force, corresponding to the maximum allowable temperatures of sublimation (King, 1970).

Accelerated freeze-drying rates using microwave energy have been successfully demonstrated on an experimental scale (Ang et al., 1977a, b; Copson, 1958; Decareau, 1970; Hoover et al., 1966; Ma and Peltre, 1975a, b).

The development of microwave freeze-dried equipment has been hampered by problems of ionization (King, 1970; Decareau, 1970; Gould and Kenyon, 1971; Ma and Peltre, 1975 a, b), uneven heating (Sale, 1974) and another problem is due to the fact that microwave energy is dissipated almost entirely to bound or unfreezable water. This limits the rate at which microwave energy can be absorbed by frozen foodstuffs and may also cause energy dissipation in the dry layer to the extent that bound water is left behind by the retreating sublimation front.

The mathematical simulation and analysis of the microwave freeze-dried was carried out by Copson (1958); Ma and Peltre (1975a, b) and Ang et al. (1977a, b, 1978). One of the major conclusions drawn from the study of Ang et al. (1977a) was that the anisotropic character of the material strongly influences the temperature profiles within the material during drying. The importance of this finding is further amplified by the coupling effect between mass transfer resistance, sample temperature and the absorption of microwave energy. It was recognized that the maximum temperature in the material determines

the quality of the product, and hence temperature profiles are just as important as the total drying time required in the optimization of the process.

Optimization of the microwave drying process was investigated by Ang et al., (1978) who concluded that: The drying rate cannot be speeded up simply by increasing microwave power over the entire run, because melt-back and/or overheating will occur. However, drying time can be reduced by a simple preprogrammed stepwise adjustment of the strength applied microwave field, or by feedback control. Temperature is a very sensitive parameter in microwave freeze-drying, but, field strength adjustment is a less sensitive variable in the optimization. Further thorough investigation is required before full-scale microwave freeze-drying is accomplished.

3. Spray drying

Spray drying is currently the most important method of dehydrating of liquid foods, pastes, and slurries yielding a high quality product. Spray drying is a well established method, whereas the basic spray dryer design has not changed to date. Recent developments have been aimed at developing spray dryer designs for specific products (Masters, 1972).

Recent improvements include the following:

a) Design features were improved (Masters, 1972)

b) Volatile retention

1) Feed preconcentration has been effective in producing products with increased volatile retention. (Kerkhof and Schoeber, 1974; Kerkhof and Thijssen, 1977).

2) Following atomization, freeze-drying has been

carried out. Although more expensive than conventional spray drying, the product quality is higher. Rehydration is also improved (King, 1974).

c) Instantization

Although agglomeration as a means of instantization is not new, schemes for more efficient agglomeration have been developed (Kjaergaard, 1974).

Foam spray drying is achieved by mixing gas with the feed before atomization or by producing gas in the feed through chemical reactions (Crosby and Weyl, 1977).

4. Continuous centrifugal fluidized bed drier

A unique drier has been described by Brown et al., (1972) which uses a centrifugal fluidized bed (CFB) concept for partial drying of piece form foods such as diced carrots, potatoes or bell peppers. The CFB drier is a cylindrical screen which rotates at about 200-350 rpm while high-velocity air flows across the chamber (Roberts et al., 1970). Centrifugal forces of 5-15 times gravity restrains the food particles which are fluidized at the inlet section of the air stream. The product can be dried at air relatively low temperature and in less time compared to other methods, due to the high heat transfer rates achieved. These high rates of heat transfer may be used during the initial stages of drying, where the process is not diffusion limited (Hanni et al., 1976).

Reduction in drying time, at lower temperatures avoids the discoloration and off-flavors which are always possible at

higher temperature and longer drying time. The CFB process should use less energy, since the drier operates above 100°C and dries with a mixture of air and superheated water vapor.

Basic designs of CFB are given by Carlson et al., (1976); Hanni et al., (1976) and recently Roberts et al., (1979).

5. Continuous explosion puffing

Originally the continuous explosion puffing (CEP) was developed by USDA at Eastern Utilization Research and Development Division. The method was described in detail by Heiland et al., (1977).

6. Continuous microwave vacuum dehydration

The method was described in detail by Meisel (1974) and Slater (1975).

7. Compression/dehydration

Compressed freeze-dried foods offer numerous space-saving advantages and exhibit remarkably normal texture properties when rehydrated. They offer a volume reduction of 75-95%. Compression also reduces the porosity of the dehydrated product resulting in: reduced susceptability to oxidation; increased mechanical strength; and reduced packaging requirements. Based on these findings, compressed foods are highly recommended for space usage, and for resupply purposes. However, further research is required in order to exploit all the advantages and optimal processes.

Although the idea of compressed and dehydrated foods is not new (Labuza, 1976; Gilles, 1974), novel compression/dehydration schemes have been developed only recently.

Every food has sufficient plasticity at a specific water activity to allow reversible compression. The conventional compression/dehydration method involves (MacKenzie and Luyet, 1969, 1972; Rahman et al., 1977):

a) Pretreatment of the food (washing, cutting into dices, blanching). In some foods (meatballs) gelatin is added for shape-retention "memory" (Anon, 1973; Konigsbacher, 1974; Randive et al., 1974, 1976).

b) Freezing

c) Freeze-drying to moisture content 1-2% moisture

d) Humidification to the desired water activity for compression. For most foods the optimum water activity ($a_w$) is 0.6-0.7. However for high sugar foods, such as cherries and other fruits, the compression is best carried out at an $a_w$ of 0.25.

e) Compression. The force required varies with the type of food but is usually between 500-1000 psia. Compression is carried out with an hydraulic press and the duration of the compression is between 5 sec. - 1 min. (Gilles, 1974).

f) Final drying is usually carried out in a conventional vacuum dryer at room temperature.

A brief list of some of the foods which have been successfully compressed after freeze-drying is as follows: beef cubes (Morgan and Farkas, 1976); blueberries (Gilles, 1974); carrots (Rahman et al., 1971); cherries (Do et al., 1976); chicken (MacKenzie and Luyet, 1972); meatballs (Anon, 1973;

Konigsbacher, 1974; Randive et al., 1976); peas (Flink, 1975); pineapple, shrimp (MacKenzie and Luyet, 1972) and spinach (Wisakowski and Burns, 1977).

Recent advances in the field of compressed foods include the following aspects:

a) Food quality - A compression scheme involving air drying in place of freeze-drying has been developed for products such as cabbage (Rahman et al., 1971). This product is a typical high moisture crispy vegetable which can not withstand the freeze-drying process which leads to a porous and mushy product upon rehydration. The method involved with the following steps (Haralampu, 1977; Rahman et al., 1977): air drying to 13% moisture content in air temperatures of 50-70%F; rehumidification with an aqueous solution of furfactant (between 60 or 80); compression with a pressure of $600 \times 10^3$ Pa which yields a compression ration of 13:1; redry to 1-2% moisture by air drying.

b) Novel applications - Compression has been applied to dry liquid food embedded in a solid matrix. This method increases the bulk density of the dry powder, and the dispersibility. The compression method is as follows (Pavey, 1975; Schafer, 1975):

The matrix is formed by mixing 99:1 parts of a sugar (lactose is preferred) to polymer (carboxymethyl-cellulose is preferred). The food powder is usually prepared by spray drying. This food powder is mixed with 13-20% of the matrix powder and in certain cases a small amount of water. The mixture is compressed into the desired shape (bar, tablet, etc.) using a compression force of 6000 psia.

This method allows the production of easily dispersible dry powders with maximum density.

c) Limited freeze-drying - This process allows foods to be dried to differing degrees of dehydration correlating to the optimum water activity for compression by adjusting the temperature of the special freeze-drying chamber. The principle of this process which eliminates the rehumidification-step is that the dehydration chamber and the condenser temperatures are separately controlled. The freeze-drying process proceeds by sublimation of the ice and desorption of the water. The sublimation process proceeds to completion and the desorption continues until the water vapor pressure in the sample chamber is in equilibrium with the ice on the condenser. Therefore, the result will be a food of uniform moisture content. The final water activity of the food decreases as the temperature difference between the chamber and the condenser increases.

Once the food has come to equilibrium, it is compressed and vacuum dried as in the conventional process.

d) Partial freeze drying and microwave heating - This method also eliminates the rehumidification step in the conventional process. It involves (Flink, 1975; Haralampu, 1977) pretreatment as in conventional methods; freezing; and conventional freeze-drying. The food is dried in the conventional manner but the process is stopped when the moisture content of the food is between 10-30%. The moisture is located in a solid ice core at the center of the food. Microwave energy is then applied in the form of 0.625 Kw for 10-60 sec. or in a conveying microwave oven

at 1.25 Kw for 1-3 min. The microwaves melt the ice core and vaporize the water which becomes distributed evenly throughout the food. The freeze-drying is controlled so that the equilibrium water activity is optimum for compression. The food is then compressed and dried to the final moisture content in a vacuum or conventional drier.

It is worth noting that the process described above is more efficient and faster than the limited freeze-dried, furthermore, no freeze-drying alterations are required.

e) Continuous compression during freeze-drying - The most recent, and only pilot studies have been carried out in our laboratory (Emami et al., 1978; Karel and Flink, 1978).

The prinicple involved is based on the fact that sufficient plasticity exists at the ice/water interface so that compression can take place in the transition zone as it receeds during the freeze-drying process. The transition zone is 1-2mm thick and varies in moisture content from 75-15%. A constant compression force is exerted on the food during the process until the final moisture content is achieved. This method produces a dehydrated and compressed food in only one step. Additionally, the compression force required is less than that in the other methods, however, the freeze-drier has to be altered to accomodate the pressure devices.

Further thorough research should be focused on the utilization of this method before any commercial usage.

## 3. Conclusion

The aims of space feeding systems will be best served by developing novel processes which integrate existing knowledge. One potential avenue is the application of microwave energy and compression in drying processes. Equally important will be the increased application of advanced preconcentration techniques with new dehydration methods so as to achieve maximum quality and diversity.

It is essential that theoretical knowledge be applied in the development of novel techniques to foods which have not been successfully dehydrated to date, such as: high quality meats, bakery products--bread and pastries, and easily dispersable powders of high bulk density. These products will be important in formulation of adequate space diets.

New technology, equipment and processing is required for providing a suitable solution to some contraints imposed by special space conditions, i.e. small scale production, pollution control, noise hazards, gravitational and rotational problems, etc.

A critical evaluation of space conditions is required before final approach is to be taken. However, existing knowledge, and projected research needs may be used for the short and intermediate time.

## E. Indicators

### I. Introduction

Shelf life of food products depends mainly on temperature of storage and the mode of failure (i.e., oxidation, browning, texture or flavor changes, etc.). Different products vary in their response to time and temperature. Thus even with "perfect" storage stability information and accelerated tests, it is necessary to assure absence of deterioration in foodstuffs which may undergo different storage conditions from those expected. Moreover, when quality control personnel and facilities are limited, an automatic indicating system capable of providing a warning is of special importance and necessity.

An indicator may be described as a device which is sensitive to time-temperature exposure and may provide an output. The ideal indicator may be characterized as a device which can integrate the time-temperature history of a storage product and provide an output related to its shelf life.

Time-temperature indicators are used mainly in the frozen food industry. Byrne (1976) reported on 46 patents related to this subject. However, only limited applications of indicators for monitoring shelf life have been attempted (Byrne, 1976; Hu, 1972; Kramer and Farquhar, 1976).

### 2. Classification

There are three different types of indicators (Byrne, 1976):

a) "Defrost Indicator" react (e.g. with a color change) when a preselected temperature is reached and/or stays above (or below) this preselected temperature for a given period of time. This type is used mainly in pharmaceuticals and other materials which can be made unusable above or below a certain temperature. This device is simple, but of limited applicability.

b) Time-Temperature Indicators react to a combination of time and temperature by undergoing a gradual color change throughout their operation life. The end point (i.e. a complete color change) is reached at a preselected combination of time and temperature. Although these devices indicate whether the preselected time-temperature combination has been reached, they do not indicate whether it has been greatly exceeded.

c) Time-Temperature Integrator/Indicator (TTI). These indicators usually respond with a color line advancing at a rate increasing with increasing temperature.

This type is used in the frozen and chilled food industry (Byrne, 1976; Kramer and Farquhar, 1976; Schone and Byrne, 1972). TTI may also be used as a monitor of equivalent storage time at a constant temperature. This is carried out by a comparison between the recommended shelf life at a reference temperature and actual storage temperature. However, if the amount of nutrients or organoleptic factor

remaining in the food is to be estimated, further information on the mode of deterioration should be known. This information includes the energy of activation of the deterioration reaction (or the value of $Q_{10}$) and the reaction order (Hayakawa, 1974; Labuza, 1976).

3. Applications

Only very limited published data are available on TTI and shelf life relationships. Hu (1972) showed that a TTI system could be used as an indicator for monitoring shelf life of a packaged food undergoing oxidation. He used a solution of sodium anthraquinone β-sulfonate and zinc dust in aqueous alkali. The resulting solution is opaque blood-red in color. By exposing the solution to air, the opaque red color is gradually changed to transparent colorless. The color change was related to oxygen which permeated the food package. A similar color approach was recently used by Jahns et al. (1976) who applied a visual enzyme test for assessing fish freshness. The test was done by developing a hypoxanthine assay into an enzyme strip test that could be used to routinely provide rapid and simple estimations of hypoxanthine in fish on a visual basis. The concentration of hypoxanthine was found earlier to correlate with fish freshness.

Evaluation of the TTI performance was done recently in England (Arnold and Cook, 1977) and in the U.S. (Kramer and Farquhar, 1976). The results in England showed that the devices tested did not show a linear response and showed

more than 10% difference in the time to reach a full-scale signal. In the U.S. (Kramer and Farquhar, 1976) the industrial indicators showed a mean coefficient of variability of about 3.8% when used as temperature-time history exposure indicators.

The approach in which a TTI may be related to the amount of nutrients or organoleptic factor remaining in the food has been restricted to only very few published research attempts. This lack of information and implementation may be explained by the complexity involved in which kinetic data and a kinetic model of the mode of failure should be first established, followed by matching the rate of a visual color change to the deterioration reaction.

## 4. Conclusion

In conclusion, if a foolproof system is desired and is to be provided for the space habitats it is highly recommended that a new approach be taken in which efforts will be focused on development of a new era of indicators. These indicators may be combined with not only the quality changes of the food stored (i.e., nutrients, flavor, oxidation, etc.) but also with the appearance of toxins and other health hazards. Due to the complexity of the food system, the complicated deterioration reactions involved, and the low concentration of the toxins, further major research is required to solve this problem.

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# A P P E N D I X

## Compilation of published stability data

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## FRUIT & VEGETABLE POWDERS

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Apple | SD | Plant slds/NFDM:40/60 | 73/2.8/A | 12-18 m | | | | Monolayer mc. 3.9% | Breene & Coulter (1967) (1) |
| | ZPD | Comminuted, + Sucrose malic acid and anti-caking agents added | 0/1.4/A | 8.7 m (F) | | ~ 2.8 | | | |
| | | | 38/1.4/A | 5.1 m (F) | | ~ 2.0 | | | |
| | | | 73/1.4/A | 5.1 m (F) | | ~ 2.4 | | HMF: doubtful criterion | |
| | | | 100/1.4/A | 5.1 m (F) | | ~ 4.5 | CA (Severe) | | |
| | | | 0/1.4/N | > 8.7 m (F) | | ~ 2.8 | | Recommended conditions: T <73°F/N | Eisenhardt et al (1969) |
| | | | 38/1.4/N | > 8.7 m (F) | | ~ 2.8 | | | |
| | | | 73/1.4/N | > 8.7 m (F) | | ~ 2.8 | | | |
| | | | 100/1.4/N | 5.1 m (F) | | ~ 4.5 | CA (Severe) | Color (ΔE) referred to original values. | |
| Apple | VD | Sucrose & citric acid added. Weeks of predesiccation: | | | | | | | |
| | | 0 | 73/2.8/A | > 12 m | ~7.60/8.0 | | No CA | Predesiccation at 73° F. Control at 0°F. ~ flavor scores after 30 weeks IPD | Turkot, et al (19:5) (2) |
| | | 0 | 100/2.8/A | 0 m (CA) | ~7.18/8.0 | | | | |
| | | 4 | 100/2.8/A | 0 m (CA) | ~7.25/8.0 | | | | |
| | | 8 | 100/2.8/A | 0 m (CA) | ~7.30/8.0 | | | | |
| | | 12 | 100/2.8/A | > 10 m | ~7.20/8.0 | | | | |
| | | 16 | 100/2.8/A | > 10 m | ~7.20/8.0 | | | | |
| | | | 100/2.0/A | > 6 m | | | No CA | Air/N/V No difference | |
| Asparagus | SD | Plant slds/NFDM:70/30 | 73/3.8/A | 6-12 m | | | | Monolayer mc 6.7% | (1) |
| Banana | SD | Plant slds/NFDM:40/60 | 73/2.8/A | 12-18 m | | | | Monolayer mc 4.0% | Mizrahi, et al (1967) |
| | SD | | 68/40% r.h/A | < 6w 4/10 (CA) | | 8/10 | | Protein: a) spray drying aid b) anticaking agent c) nutritional supplement | (3) |
| | | | 86/40% r.h/A | < 6w 5/10 (CA) | | 7/10 | | | |
| | | | 104/40% r.h/A | < 6w 1/10 (CA) | | 3/10 | | | |
| | | | 68/60% r.h/A | < 6w 1/10 (CA) | | 7/10 | | | |
| | | | 86/60% r.h/A | < 6w 2/10 (CA) | | 5/10 | | | |
| | | | 104/60% r.h/A | < 6w 1/10 (CA) | | 1/10 | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Banana | SD | + Isoelectric soybean protein (4% d.b.) added | 68/40% r.h/A | > 6w 10/10 (CA) | Taste Acceptable | 10/10 | | | (3) |
| | | | 86/40% r.h/A | > 6w 9/10 (CA) | | 10/10 | | | |
| | | | 104/40% r.h/A | < 6w 7/10 (CA) | | 7/10 | | | |
| | | | 68/60% r.h/A | < 6w 6/10 (CA) | | 8/10 | | | |
| | | | 86/60% r.h/A | < 6w 4/10 (CA) | | 8/10 | | | |
| | | | 104/60% r.h/A | < 6w 1/10 (CA) | | 5/10 | | | |
| | SD | + Isoelectric soybean protein (10% d.b.) added | 68/40% r.h/A | > 6w 10/10 (CA) | | 10/10 | | | (3) |
| | | | 86/40% r.h/A | > 6w 9/10 (CA) | | 9/[illegible] | | | |
| | | | 104/40% r.h/A | < 6w 2/10 (CA) | | 6/[illegible] | | | |
| | | | 68/60% r.h/A | < 6w 3/10 (CA) | | 8/10 | | | |
| | | | 86/60% r.h/A | < 6w 2/10 (CA) | | 8/10 | | | |
| | | | 104/60% r.h/A | < 6w 1/10 (CA) | | 2/10 | | | |
| | SD | + Isoelectric soybean protein (20% d.b.) added | 68/40% r.h/A | > 6w 10/10 (CA) | | 10/10 | | | (3) |
| | | | 86/40% r[illegible]/A | > 6w 9/10 (CA) | | 10/10 | | | |
| | | | 104/40% r.h/A | < 6w 7/10 (CA) | | 7/10 | | | |
| | | | 68/60% r.h/A | < 6w 4/10 (CA) | | 9/10 | | | |
| | | | 86/60% r.h/A | < 6w 3/10 (CA) | | 8/10 | | | |
| | | | 104/60% r.h/A | < 6w 1/10 (CA) | | 4/10 | | | |
| Blueberry | SD | Plant slds/NFDM:40/60 | 73/1.7/A | 4-6 m | | | | Monolayer m.c. 3.5% | (1) |
| | SD | Plant slds/NFDM:50/50 | 73/2.0/A | 4-6 m | | | | Monolayer m.c. 5.8% | (1) |
| Boysenberry | SD | Plant slds/NFDM:40/60 | 73/3.6/A | | | | | Monolayer m.c. 4.1% | (1) |
| Broccoli | SD | Plant slds/NFDM:75/25 | 73/4.5/A | 4-6 m | | | | Monolayer m.c. 6.2% | (1) |
| Cantaloupe | SD | Plan slds/NFDM:50/50 | 73/2.1/A | 4-6 m | | | | Monolayer m.c. 6.3% | (1) |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Carrot | SD | Plant slds/NFDM:50/50 | 73/4.5/A | 2-4w | | | | Monolayer m.c. 4.1% | (1) |
| | DD | 2.5% Rice flour + 0.05% $Na_2S_2O_5$ added | 70-114/?/A | ∿ 6 m (F) | | | β-carotene: 70.8-72.5% | package: Polyethyl-ene + cans | Mohamad, et al. (1973) |
| Caulif-flower | SD | Plant slds/NFDM:33/67 | 73/5.1/A | 6-12 m | | | | Monolayer m.c. 4.9% | (1) |
| Celery | SD | Plant slds/NFDM:70/30 | 73/3.4/A | 6-12 m | | | | Monolayer m.c. 11.8% | (1) |
| Cherry | SD | Plant slds/NFDM:50/50 | 73/6.0/A | 6- 8 w | | | | Monolayer m.c. 6% | (1) |
| Cranberry | SD | Plant slds/NFDM:50/50 | 73/3.7/A | 6- 8 w | | | | Monolayer m.c. 6.3% | (1) |
| Cranberry | DD | | 34/3.4/A | > 400d 14.0 (s) | | | | Jelly Sag (S) = % No Jelly = NJ | Kertesz, et al (1963) |
| | | | 54/3.4/A | > 400d 18.0 (s) | | | | | |
| | | | 90/3.4/A | > 400d 22.5 (s) | | | | | |
| | | | 100/3.4/A | ∿ 400d 40.0 (s) | | | | | |
| | | | 113/3.4/A | 120d NJ | | | | | |
| | | | 131/3.4/A | 10d NJ | | | | | |
| | | | 34/4.7/A | > 90d 21.5 (s) | | | | | |
| | | | 90/4.7/A | > 90d 29.8 (s) | | | | | |
| | | | 100/4.7/A | < 90d NJ | | | | | |
| | | | 90/8.7/A | 88d NJ | | | | | |
| | | | 100/8.7/A | 61d NJ | | | | | |
| Grape | VD | Sucrose and citric acid added. No predesiccation | 0/3.2/V | Control OK | | | Caking | | (2) |
| | | | 73/3.2/A | (CA) | 7.7/8.0 | | Signif.(CA) | Limit of accept-ability: 6 (F) | |
| | | | 73/3.2/V | (CA) | 7.7/8.0 | | Signif.(CA) | Flavor scores after 6 months. | |
| | | | 100/3.2/A | 0 m (CA) | 5.9/8.0 | | Severe (CA) | | |
| | | | 100/3.2/V | 0 m (CA) | 5.8/8.0 | | Severe (CA) | | |
| | | +IPD | 73/2.5/A | >12 m | | | | | |
| | | +IPD | 100/1.7/A | > 6 m | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Grape (cont'd) | VD | Predesiccation at 73°, weeks of predesiccation: | | | | | | | |
| | | 0 | 0/2.4/A | > 10 m | | | No CA | ∿ flavor scores after 30 weeks | (2) |
| | | 0 | 73/2.4/A | > 10 m | ∿ 7.5 /8.0 | | No CA | | |
| | | 0 | 100/2.4/A | 0 m (CA) | ∿ 6.80/8.0 | | | | |
| | | 4 | 100/2.4/A | 0 m (CA) | ∿ 7.11/8.0 | | | | |
| | | 8 | 100/2.4/A | 0 m (CA) | ∿ 7.10/8.0 | | | | |
| | | 12 | 100/2.4/A | > 10 m | ∿ 7.08/8.0 | | No CA | | |
| | | 16 | 100/2.4/A | > 10 m | ∿ 7.2 /8.0 | | No CA | | |
| | VD | Predesiccation at 35°: | | | | | | | |
| | | 0 | 35/2.4/A | > 10 m | ∿ 7.8 /8.0 | | No CA | ∿ flavor scores after 30 weeks | (2) |
| | | 0 | 100/2.4/A | 0 m (CA) | ∿ 6.85/8.0 | | | | |
| | | 4 | 100/2.4/A | 0 m (CA) | ∿ 7.10/8.0 | | | | |
| | | 8 | 100/2.4/A | 0 m (CA) | ∿ 7.20/8.0 | | | | |
| | | 12 | 100/2.4/A | > 10 m | ∿ 7.00/8.0 | | No CA | | |
| | | 16 | 100/2.4/A | > 10 m | ∿ 7.25/8.0 | | No CA | | |
| Grape Juice | SD | Plant slds/NFDM:40/60 | 73/2.5/A | > 9 m | | | | Monolayer m.c. 6.1% | (1) |
| Grape Thompson | SD | Plant slds/NFDM: 40/60 | 73/2.7/A | 4-6 m | | | | Monolayer m.c. 6.0% | (1) |
| Grapefruit | FMD | 58° Brix, methyl-cellulose and soya albumin added | 70/1%/N | | | | | | Berry, et al. (1966) |
| | | | Drying T 160° | 36 w (F) | | | | | |
| | | | Drying T 170° | 34 w (F) | | | | | |
| | | | Drying T 180° | 32 w (F) | | | | | |
| | | | Drying T 190° | 27 w (F) | | | | | |
| | | | 85/1%/N | | | | | | |
| | | | Drying T 160° | 6 w (F) | | | | | |
| | | | Drying T 170° | 5 w (F) | | | | | |
| | | | Drying T 180° | 7 w (F) | | | | | |
| | | | Drying T 190° | 12 w (F) | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Green Bean | SD | Plant slds/NFDM:60/40 | 73/3.6/A | > 5 m | | | | Monolayer mc. 4% | (1) |
| | | | | | | | Ascorbic Acid | | |
| Guava | FD | Pasteurized, | 73/0.51-0.73/N | > 6 m | | | 98.7% | | Foda, et al. (1970) |
| | | Nonpasteurized | 73/0.51-0.75/N | < 6 m | | | 97.9% | | |
| | | Lag Time (Days) | | | | Browning Rate | | | |
| Lemon | FD | 30 | 77/0r.h/A | | | $1.17 \times 10^{3}$ | | Browning Rate: A/day | Kopelman, et al. (1977) |
| | | 6 | 95/0r.h/A | | | $3.2 \times 10^{3}$ | | A: absorbance | |
| | | 25 | 77/0.06/A | | | $1.42 \times 10^{3}$ | | $CO_2$ as an early indicater of browning rate & intensity | |
| | | 5 | 95/0.06/A | | | $5.5 \times 10^{3}$ | | | |
| | | 20 | 77/0.11/A | | | $1.9 \times 10^{3}$ | | | |
| | | 5 | 95/0.11/A | | | $8.2 \times 10^{3}$ | | | |
| | | 10 | 77/0.22/A | | | $3.5 \times 10^{3}$ | | | |
| | | 4 | 95/0.22/A | | | $15.2 \times 10^{3}$ | | | |
| | | 30 | 77/0.0 /N | | | $0.62 \times 10^{3}$ | | | |
| | | 7 | 95/0.0 /N | | | $3.2 \times 10^{3}$ | | | |
| | | 25 | 77/0.06/N | | | $1.0 \times 10^{3}$ | | | |
| | | 5 | 95/0.06/N | | | $5.7 \times 10^{3}$ | | | |
| | | 20 | 77/0.11/N | | | $1.25 \times 10^{3}$ | | | |
| | | 5 | 95/0.11/N | | | $7.3 \times 10^{3}$ | | | |
| | | 10 | 77/0.22/N | | | $2.75 \times 10^{3}$ | | | |
| | | 4 | 95/0.22/N | | | $12.5 \times 10^{3}$ | | | |
| | | | 39/0-0.22/N | >4 m | | -- -- -- | | | |
| Lemonade | VPD | 67.5° Brix, IPD | 70/1.7→0.5%/V | >3 m (F + CO) | | | | 59% sucrose, 8.3% lemon juice concentrate, 28.1% lemon juice and 4.6% added water | Notter, et al. (1955) |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
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| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Material | Drying | Additional Treatment | Storage Conditions T($^{o}$F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Lima bean | SD | Plant slds/NFDM:65/35 | 73/3.7/A | | | | | Monolayer m.c. 6.0% | (1) |
| Lima bean | DD | Cooked dried | 72/10/A | 51 days (F) | | | | Control at ‡23° C/N. Time for 75% correct answer | Burr, et al (1969) |
| | | | 72/ 5/A | 59 days (F) | | | | | |
| | | | 72/10/N | 98 days (F) | | | | | |
| | | | 72/ 5/N | 190 days (F) | | | | | |
| | | | 72/ 4/N | 225 days (F) | | | | | |
| | | Plus 3 ppm BHT | 72/ 4/N | 325 days (F) | | | | | |
| | | | 100/ 5/A | 30 days (F) | | | | | |
| | | | 100/ 4/N | 175 days (F) | | | | | |
| | | Plus 3 ppm BHT | 100/ 4/N | 219 days (F) | | | | | |
| | | | | | | | Ascorbic acid | | |
| Mango | FD | Single strength | 99/1-1.5/N | 3 m. (CO + CA) | | | ∿ 35% | mango (Raspuri ) addition of sucrose increased shelf life | Ammu, et al (1977) |
| | | 15° Brix | 99/1-1.5/N | 4 m. (CO + CA) | | | ∿ 46% | | |
| | | 20° Brix | 99/1-1.5/N | 4 m (CO + CA) | | | ∿ 44% | | |
| | | | | | | Browning | Protein | | |
| Navy bean | DD | | 99/ 4/A | stored for 28 d | | 13/11.0 | 21.8/24 | 1% m.c.→ 11% R.H. (below monolayer m.c.) 5.23% m.c.→ 23% R.H. (at monolayer m.c.) monolayer samples browned more & lost more sol. protein than samples below the monolayer. Lipid oxidation & browning as major problems. Control at -20° C. | Love & Duggan (1978) |
| | | | 99/ 4/A | stored for 28 d | | 12.3/11.0 | 21.4/24 | | |
| | | | 99/5.23/N | stored for 29 d | | 12.6/11.0 | 19.9/24 | | |
| | | | 99/5.23/N | stored for 29 d | | 15.2/11.0 | 22.1/24 | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T($^{o}$F)%MC/Atm. | Time required for appearance of the earliest defects (quality affected | FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Olallie-berry | SD | Plant slds/NFDM:40/60 | 73/5.3/A | 4-6 m | | | | Monolayer mc 4.8% | (1) |
| Onion | | Commercial dehydrated and ground | 95/7.0/A | 72 h (CA) | | | | + anticaking agents | Peleg & Mannheim (1969) |
| | | | 95/3.0/A | ∿ 30 d (CA) | | | | No anticaking agents | |
| | | | 95/4.5/A | ∿ 72 h (CA) | | | | " | |
| | | | 86/4.5/A | 7-10 d (CA) | | | | " | |
| | | | 77/4.5/A | 7-10 d (CA) | | | | " | |
| | | | 59/4-5/A | ∿ 6 m (CA) | | | | " | |
| | | Commercial dehydrated and ground | 95-99/6-7/A | 72 h (CA) | | | | No anticaking agents | Granouskaya, et al (1972) |
| | | | 95-99/6-7/A | 12 m (CA) | | | | 2% Ca stearate | |
| Orange | SD | Plant slds/NFDM:45/55 | 73/2.2/A | 6-12 m | | | | Monolayer m.c. 5.4% | (1) |
| | | m.c. g $H_2O$/100 g slds | | | | Browning Rate | | | |
| | | $A_w$ .54 | 99/16/A/N | | | ∿ 8 x $10^2$ | | Color: browning rate, OD units/ week (alcohol extract, 390nμ | Karel & Nickersson (1964) |
| | | $A_w$ .44 | 99/11/A/N | | | ∿ 4.7 x $10^2$ | | $O_2$ had no effect on browning and ascorbic acid content | |
| | | $A_w$ .32 | 99/6.5/A/N | | | ∿ 3.0 x $10^2$ | | | |
| | | $A_w$ .20 | 99/4.5/A/N | | | ∿ 1.5 x $10^2$ | | | |
| | | $A_w$ .11 | 99/2.7/A/N | | | ∿ 0.7 x $10^2$ | | | |
| | | $A_2$ .06 | 99/1.0/A/N | | | ∿ 0.4 x $10^2$ | | | |
| | FMD | 60$^{o}$ Brix | 0/?/N | > 10 m | | | | | Gee et al (1969) |
| | | | 70/?/N | > 10 m | | | | | |
| | | | 90/?/N | 7 m (F) | | | | | |

| | | | | | | | | | | | |
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| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
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Fruit & Vegetable Powders (continued)

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Orange (cont'd) | FD | | 70/.5-1./V | 3 m (F) | | | | Conditioning: 78 days at 77°F | Notter, et al (1959) |
| | | | 100/.2-9/V | 30 d (F) | | | | | |
| | FMD | ~50° Brix + Citric acid | 70/ /A? | ~26 w | | | | Control -5° F More acid juices had better stability | Berry, et al (1972) |
| | | pH 4.0 - 6.0 | 85/ / | 2-4 w | | | | | |
| | | pH 3.7 | 85/ / | 5 w | | | | | |
| | | pH. 3.3 | 85/ / | 13 w | | | | | |
| | VD | Corn syrup solids, orange oil in sorbitol, IPD, + $SO_2$ | 70/3.1/V | > 12 m (F) | 8.2/10 | | Ascorbic Acid Retention | Flavor 10 is highly palatable and 6 is limit of acceptability. *samples stored 75 days at 70° F prior to storage at 100° F | Mylne & Seamans (1954) |
| | | | *100/3.1/V | > 6 m (F) | 6.9/10 | | | | |
| | | - $SO_2$ | 70/3.0/V | > 12 m (F) | 8.1/10 | | > 90% | | |
| | | | *100/3.0/V | > 6 m (F) | 6.5/10 | | ~90% | | |
| | FD | 13% total soluble solids | 73/1.16-3.93/N | >6 m | | | 95.8% | IPD | Foda, et al (1970) |
| | | 20% total soluble solids | 73/2.23-3.96/N | >6 m | | | 95.4% | | |
| | | 36% total soluble solids | 73/2.45-3.41/N | <6 m | | | 93.8% | | |
| Pea bean | DD | Soaked & retorted | 73/4-5/A | > 12 m (F) | | | | | Baker, et al (1976) |
| | | | 73/>6/A | < 12 m (F) | | | | | |

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| | | | | | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Material | Drying | Additional Treatment | T(°F)%MC/Atm. | (quality affected | FLAVOR | COLOR | OTHERS | Comments | Ref. |
| Sweet Pea | SD | Plant slds/NFDM/100/0 | 73/2.8/A | 12-18 m | | | | Monolayer M.C. 5% | (1) |
| Peach | SD | Plant slds/NFDM/30/70 | 73/2.8/A | 6- 8 w | | | | Monolayer m.c. 5.0% | (1) |
| Pineapple | SD | Plant slds/NFDM/40/60 | 73/2.5/A | 8 m | | | | Monolayer m.c. 6.2% | (1) |
| | VD | 47° Brix, IPD | 100/ /A | < 30 d (F) | - - - | 120/63 | | Soluble color: Klett units | Notter et al (1958) |
| | | | 70/1.2-2.4/A | > 12 m (F) | OK | 67/63 | | Vacuum packing | |
| | | | 77/ /A | >8.5 m (F) | OK | 64/63 | | was not found | |
| | | | 90/ /A | ≤ 30 d (F) | | | Ascorbic Acid | necessary for flavor retention. | |
| | FD | Natural | 99/1-1.5/N | 2 m (CO + CA) | | | 50% | | Ammu et al (1977) |
| | | 15° Brix | 99/1-1.5/N | 4 m (CO + CA) | | | 48% | | |
| | | 20° Brix | 99/1-1.5/N | 3 m (CO + CA) | | | < 50% | | |
| Pinto bean | DD | | 50/6.2/A | 15.6 w (F) | | | | | Guadagni et al (1975) |
| | | | 50/6.2/N | 83 w (F) | | | | | |
| | | | 70/6.2/A | 9.2 w (F) | | | | | |
| | | | 70/6.2/N | 42.0 w (F) | | | | | |
| | | | 90/6.2/A | 5.8 w (F) | | | | | |
| | | | 90/6.2/N | 23.0 w (F) | | | | | |
| Pumpkin | SD | Plant slds/NFDM:50/50 | 73/2.9/A | 6-8 w | | | | Monolayer m.c. 4.6% | |
| | | | 73/2.9/N | 9 m | | | | Monolayer m.c. 4.6% | (1) |
| Raspberry | SD | Plant slds/NFDM:40/60 | 73/3.8/A | 6-12 m | | | | Monolayer m.c. 5.0% | (1) |
| Rhubarb | SD | Plant slds/NFDM:40/60 | 73/4.0/A | 4-6 m | | | | Monolayer m.c. 5.9% | |
| Spinach | SD | Plant slds/NFDM/70/30 | 73/2.2/A | 4-6 m | | | | Monolayer m.c. 6.1% | |
| Strawberry | SD | Plant slds/NFDM:35/65 | 73/2.7/A | 4-6 m | | | | Monolayer m.c. 4.9% | (1) |

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| Food Material | Method of Drying | Additional Treatment | Storage Conditions T($^{o}$F)%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Sweet Corn | SD | Plant slds/NFDM:70/25 | 73/2.9/A | 12-18 m | | | | Monolayer m.c. 6.8% | (1) |
| Tomato | SD | Plant slds/NFDM:30/70 | 73/5.6/A | 6- 8 w | | | | Monolayer m.c. 4.2% | (1) |
| | SD | | 73/5-6/N | 11 m | | | | " | " |
| | VD | IPD $SO_2$ | 100/2.7-2.9/A | 6 w (CO) | 5.04/1.80 | 5.05/3.69 | | | Wong, et al (1956) |
| | | $SO_2$ | 90/2.7-2.9/A | 6 w (F+CO) | 4.72/2.78 | 6.05/4.10 | | | |
| | | $SO_2$ | 70/2.7-2.9/A | < 6 w (F+CO) | 4.40/2.96 | 5.90/3.31 | | | |
| | | | 70/2.7-2.9/N | > 6 m (CO) | 1.84/1.83 | 3.0/2.14 | | Control N/10$^{o}$ F | |
| | | | 90/2.7-2.9/N | <12 w (F) | 2.78/1.58 | 2.47/2.63 | | Rank 1-5 | |
| | | | 100/2.7-2.9/N | > 6 w (F) | 3.65/2.00 | 2.31/2.55 | | 1 = flavor & color closest to control. Time required for significant difference from control. | |
| | FMD | IPD | 36/ 3/A | | | 30%--202d | | Soluble color percent. | Lovric et al (1970) |
| | | | 68/ 3/A | | | 15% - " | | | |
| | | | 36/ 3/N | | | 72 " | | | |
| | | | 68/ 3/N | | | 70 " | | | |
| | FMD | IPD | 68/1.2-1.5/N | 6- 8 m | | | | | Boscovic |
| | SD | No IPD | 70/1.8/A | < 3 m (F) | 5.7/3.1 | - - - | | F: 1-7, where 7 flavor is most different from control. | Miers, et al (1958) |
| | | | 70/1.8/N | ~ 12 m | 3.6/4.0 | - - - | | | |
| | | | 70/1.8/CO | ~ 12 m | 4.3/4.0 | - - - | | | |
| | | | 90/1.8/A | < 1.5 m (F) | 5.4/3.1 | 5.2/4.5 | | CO: 1-7, where 7 lightest color time required for significant difference from control | |
| | | | 90/1.8/N | < 1.5 m (CO) | 4.0/3.1 | 2.5/4.5 | | | |
| | | | 90/1.8/CO | < 1.5 m (F + CO) | 4.9/3.1 | 2.6/4.5 | | | |
| | | | 100/1.8/A | < 1.5 m (F) | 5.2/3.8 | 4.9/4.4 | | | |
| | | | 100/1.8/N | < 1.5 m (CO) | 4.4/2.8 | 2.6/4.4 | | | |
| | | | 100/1.8/CO | < 3 m (F+CO) | 4.6/3.0 | 2.7/4.3 | | | |

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| Food Material | of Drying | Additional Treatment | Storage Conditions T(°F)%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded | | | | |
| Tomato (cont'd) | SD | IPD | 70/1.3/A | < 1.5 m (F) | 5.8/3.1 | - - | | | |
| | | | 70/1.8/N | >12.0 m | 3.0/4.0 | - - | | | |
| | | | 70/1.8/CO | >12.0 m | 2.8/4.0 | - - | | | |
| | | | 90/1.8/A | < 1.5 m (F) | 4.8/3.1 | 4.3/4.5 | | | |
| | | | 90/1.8/N | >12.0 m | 3.1/2.6 | 5.0/5.0 | | | |
| | | | 90/1.8/CO | >12.0 m | 3.7/2.6 | 4.3/5.0 | | | |
| | | | 100/1.8/A | < 3.0 m (F) | 4.8/3.0 | 3.9/4.3 | | | |
| | | | 100/1.8/N | >12.0 m | 3.0/2.0 | 4.9/5.5 | | | |
| | | | 100/1.8/CO | >12.0 m | 2.6/2.0 | 5.3/5.5 | | | |

| | | | | | | | | | | | |
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|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Texture | Rehydrated. | |
| Apple | FD | Sucrose preconcentrated | 72/0 r.h/V | > 18 m (F) | 7.08 | | 7.17 | hedonic | Karel & |
| | | | 39/0 r.h/A | > 18 m (F) | 6.77 | | 6.75 | scale 1-9 | Flink |
| | | | 72/0 r.h/A | > 18 m (F) | 7.46 | | 6.67 | 5: limit of | (1976) |
| | | | 99/0 r.h/A | > 16 w (F) | 6.50 | | 6.64 | acceptability | |
| | | | 72/10r.h/A | > 8 w (F) | 6.92 | | 6.42 | Flavor | |
| | | | 99/10r.h/A | > 5 w (F) | 6.60 | | 6.42 | (rehydrated) | |
| | | | 72/43r.h/A | < 2 w (T) | 5.75 | | 3.85 | | |
| | | | 99/43r.h/A | < 2 w (T) | 5.83 | | 3.62 | | |
| Apricots | DD | Apricot sheets | | | | | β-carotene | | Bolin & |
| | | 0.3% $SO_2$ | 90/12/A | ~ 13 w (CO) | | ~ 36/48 | 82% ret. | Color given as | Stafford |
| | | 0.10% $SO_2$ | 90/12/A | < 8 w (CO) | | ~ 27.5/46 | 75% | reflectance(after | (1974) |
| | | 0.03% $SO_2$ | 90/12/A | < 5 w (CO) | | ~ 22.5/46 | 70% | 13 weeks) | |
| | | 0% $SO_2$ | 90/12/A | ~ 4 w (CO) | | ~ 22.5/44 | 68% | | |
| | SunD+AD | | 120/25/N | ~ 17 d | | | | 2800 ppm $SO_2$ | Stadtman, |
| | | 29 mg $O_2$ | 120/25/O | ~ 15 d | | | | for all samples. | et al |
| | | 58 mg $O_2$ | 120/25/O | ~ 13 d | | | | Oxygen/100 gms | (1946) |
| | | 200 mg $O_2$ | 120/25/O | ~ 11.7 d | | | | of sample | |
| | | | 120/10/N | ~ 11.6 d | | | | | |
| | | 29 mg $O_2$ | 120/10/O | ~ 11.1 d | | | | | |
| | | 58 mg $O_2$ | 120/10/O | ~ 11 d | | | | | |
| | | 200 mg $O_2$ | 120/10/O | ~ 11 d | | | | | |
| | | 2,000 ppm $SO_2$ | 120/14.2/O | ~ 7.3 d | | | | For all of these | |
| | | | 120/21.3/O | ~ 8.4 d | | | | samples, the $O_2$ | |
| | | 5,000 ppm $SO_2$ | 120/14.2/O | ~ 12.1 d | | | | level was 47 ml/100 | |
| | | | 120/21.3/O | ~ 14.1 d | | | | grams of sample | |
| | | 8,000 ppm $SO_2$ | 120/14.2/O | ~ 16.4 d | | | | | |
| | | | 120/21.3/O | ~ 19.9 d | | | | | |

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|---|---|---|---|---|---|---|---|---|---|
| Avocado | FD | | 40/2.0/N/V | 48 w (F) | | | | Avocado salad, 88.6% avocado meat Peroxide value of little assistance in predicting quality | Lime (1969) |
| | | | 68/2.0/N/V | 16 w (F) | | | | | |
| | | | 100/2.0/N/V | 3 w (F) | | | | | |
| | | | 0/2.0/A | 48 w (F) | | | | | |
| | | | 40/2.0/A | 16 w (F) | | | | | |
| | | | 68/2.0/A | 8 w (F) | | | | | |
| | | | 100/2.0/A | 2 w (F) | | | | | |
| | FD | | 99/0.2/ | | | | | After 15 days min. rancidity was observed in the 1-2% moisture range | Lladser & Pinaga (1975) |
| | | | 99/0.7/ | | | | | | |
| | | | 99/1.0/ | | | | | | |
| | | | 99/2.0/ | | | | | | |
| | | | 99/3.3/ | | | | | | |
| | | | 99/4.8/ | | | | | | |
| | | | | | | | Ascorbic Acid | | |
| Banana | FD | Slow freezing | 68/2/V | > 12 m | 6.9/7.3 | 7.4/7.6 | $2.94\times10^{-3}$ | Ascorbic acid degradation: day-1. 5-6 = fair 7-8 = good Formation of water-soluble pigments as a criterion of storage. | Maia & Luh (1970) |
| | | | 86/2/V | > 12 m | 6.2/7.3 | 5.4/7.6 | $3.92\times10^{-3}$ | | |
| | | Quick freezing | 68/3/V | > 12 m | 7.4/6.8 | 7.7/6.0 | $2.81\times10^{-3}$ | | |
| | | | 86/2/V | > 12 m | 6.1/6.8 | 5.8/6.7 | $3.63\times10^{-3}$ | | |
| | | | | | | Absorbance | Ascorbic Acid | | |
| | FD | Untreated | 82/0.70/A | > 180 d (CO) | | ~ 0.020 | 66% | After 173 days absorbance at 430 mµ Time 0:0.029 | Draudt & Huang (1966) |
| | | | 82/3.43/A | > 180 d (CO) | | ~ 0.032 | 57.1% | | |
| | | | 82/5.44/A | > 180 d (CO) | | ~ 0.033 | 37.0% | | |
| | | | 82/8.04/A | < 180 d (CO) | | ~ 0.045 | 21.88% | | |
| | | | 82/10.02/A | < 180 d (CO) | | ~ 0.07 | 18.8% | | |
| | | | 82/19.14/A | < 50 d (CO) | | ~ 0.06 | 8.5% | | |
| | | $SO_2$ treated | 82/0.93/A | > 180 d (CO) | | ~ 0.010 | 85.0% | Distinct color bleaching in samples with moisture content below 7.91%. | |
| | | | 82/3.74/A | > 180 d (CO) | | ~ 0.021 | 87.8% | | |
| | | | 82/5.99/A | > 180 d (CO) | | ~ 0.021 | 88.6% | | |
| | | | 82/7.91/A | > 180 d (CO) | | ~ 0.021 | 66.6% | | |
| | | | 82/9.40/A | < 180 d (CO) | | ~ 0.034 | 21.8% | | |
| | | | 82/16.16/A | < 180 d (CO) | | ~ 0.033 | 14.7% | | |

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| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Bananas (cont'd) | AD | Untreated | 55/17.5/A | > 12 m (F) | | 2.59/1.87 | | Color value = | Brekke & Allen (1967) |
| | | $SO_2$ treated | 55/17.5/A | > 12 m (F) | | 1.75/1.03 | | | |
| | FD | Untreated | 55/3.6/A | > 12 m (F) | | 0.94/0.59 | | Absorbance / dilution factor x | |
| | | $SO_2$ treated | 55/3.6/A | > 12 m (F) | | 0.53/0.40 | | Light path | |
| | DD | Untreated | 55/2.7/A | > 12 m (F) | | 1.34/1.31 | | | |
| | | $SO_2$ treated | 55/2.7/A | > 12 m (F) | | 1.22/1.22 | | | |
| | AA | Untreated | 75/17.5/A | 6 m (F) | | 3.66/1.87 | | | |
| | | $SO_2$ treated | 75/17.5/A | 9 m (F) | | 4.64/1.03 | | | |
| | FD | Untreated | 775/3.6/A | > 12 m (F) | | 1.41/0.59 | | | |
| | | $SO_2$ treated | 75/3.6/A | > 12 m (F) | | 0.57/0.40 | | | |
| | DD | Untreated | 75/2.7/A | > 12 m (F) | | 1.49/1.31 | | | |
| | | $SO_2$ treated | 75/2.7/A | > 12 m (F) | | 1.36/1.22 | | | |
| | AD | Untreated | 100/17.5/A | 2 w (F) | | 2.93/1.87 | | | |
| | | $SO_2$ treated | 100/17.5/A | 2 w (F) | | 2.30/1.03 | | | |
| | FD | Untreated | 100/3.6/A | 4 m (F) | | 3.24/0.59 | | | |
| | | $SO_2$ treated | 100/3.6/A | 6 m (F) | | 2.64/0.40 | | | |
| | DD | Untreated | 100/2.7/A | 6 m (F) | | 4,00/1,31 | | | |
| | | $SO_2$ treated | 100/2.7/A | 6 m (F) | | 2,98/1,22 | | | |
| | DD | Flakes $SO_2$ treated | 100/2.4/A | < 11 w (CO) | 6.2 | 0.090 | | Monolayer value: | Melpar (1964) |
| | | | 100/3.0/A | < 11 w (CO) | 5.8 | 0.115 | | 50% RH & 9.5% $H_2O$ | |
| | | | 100/5.3/A | < 11 w (CO) | 6.7 | 0.160 | | Optical density | |
| | | | 100/8.3/A | < 11 w (CO) | 5.8 | 0.250 | | 420 mμ Flavor | |
| | | | 100/13.3/A | < 11 w (CO) | 5.8 | 0.310 | | was acceptable | |
| | | | 100/21.8/A | < 11 w (CO) | 5.8 | 0.310 | | during the study COLOR PROBLEM | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | State of Other Factors at Time of Unacceptability or at Maximum Time recorded | | |
| | | | | | | | Ascorbic Acid | | |
| Mango | FD | Fast freezing (1) | 68/ /V | | | | 65% | After 12 m (1) had better color, flavor & aroma | Aliaga & Luh (1973) |
| | | (2) | 86/ / | | | | 44% | | |
| | | Slow freezing (3) | 68/ /V | | | | 85% | | |
| | | (4) | 86/ / | | | | 72% | | |
| | | | | | | Reflectance | | | |
| Peaches | Sun D? | $SO_2$ | 70/60 r.h/N | >18 m (CO) | | ~ 32 | | Initial m.c.31% Reflectance (L) at time 0: 42. 30 considered limit of acceptability. | Bolin & Stafford (1976) |
| | | | 70/60 r.h/V | >18 m (CO) | | ~ 30 | | | |
| | | | 70/60 r.h/A | <18 m (CO) | | 27.5 | | | |
| | | | 90/60 r.h/N | < 6 m (CO) | | 27.5 | | | |
| | | | 90/60 r.h/V | < 6 m (CO) | | 27.0 | | | |
| | | | 90/60 r.h/A | < 6 m (CO) | | 20.5 | | | |
| | | | | | | | Texture | | |
| | FD | Osmotically treated 60% sugar | 77/ /V | >16 w | 7.30 | | 6.70 | Hedonic scale: 1-9 FLAVOR (REHYDRATED). 5 limit of acceptability. | Karel & Flink (1975) |
| | | | 39/ 0 r.h/A | >16 w | 6.80 | | 6.60 | | |
| | | | 77/ 0 r.h/A | >16 w | 6.60 | | 6.30 | | |
| | | | 99/ 0 r.h/A | < 8 w (F) | 4.85 | | 5.82 | | |
| | | | 77/10 r.h/A | > 8 w | 6.15 | | 6.55 | | |
| | | | 99/10 r.h/A | > 4 w | 5.25 | | 6.33 | | |
| | | | 77/43 r.h/A | < 2 w (T) | 5.08 | | 3.33 | | |
| | | | 99/43 r.h/A | < 2 w | 3.67 | | 2.25 | | |
| | | | | | | | Ascorbic Acid | | |
| | FD | Untreated | 82/0.72/A | > 6 m (CO) | | ~0.022 | 97.6% | optical absorbance at 430 mμ (after 241 days) ascorbic acid retention after 228 days. | Draudt & Huang (1966) |
| | | | 82/2.04/A | > 6 m (CO) | | | 85.3% | | |
| | | | 82/3.40/A | > 6 m (CO) | | ~0.024 | 83.3% | | |
| | | | 82/5.36/A | > 6 m (CO) | | ~0.035 | 62.0% | | |
| | | | 82/8.43/A | <100 d (CO) | | ~0.072 | 35.4% | | |
| | | | 82/12.67/A | <100 d (CO) | | ~0.190 | 26.9% | | |
| | | Blanched | 82/1.00/A | > 6 m (CO) | | ~ 0.04 | 100.3% | After 229 days (ascorbic acid) | |
| | | | 82/12.0/A | <100 d (CO) | | ~ 0.14 | 31.9% | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
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| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
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Fruits (continued)

| Food Material | Method of Drying | Additional Treatment | Storage Conditions $T(^{\circ}F)$/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded | | | | |
| | | | | | | | Ascorbic Acid | | |
| Peaches | FD | $SO_2$ | 82/0.90/A | > 6 m (CO) | | ∿ 0.025 | 95.6% | After 229 days (Ascorbic acid) | |
| | | | 82/2.06/A | > 6 m (CO) | | ∿ 0.028 | 98.7% | | |
| | | | 82/3.42/A | > 6 m (CO) | | ∿ 0.030 | 78.7% | | |
| | | | 82/5.35/A | > 6 m (CO) | | ∿ 0.033 | 67.0% | | |
| | | | 82/8.52/A | < 100 d (CO) | | ∿ 0.062 | 40.5% | | |
| | | | 82/11.50/A | < 100 d (CO) | | ∿ 0.122 | 28.9% | | |
| | FL | "Zero oxygen" | 100/1.5/H-N | 6 m (F) | | | | | Bishov, et al. (1971) |
| | | | 100/1.5/O | 1 m (F) | | | | | |
| | FD | Vacuum: 27 inches | 40/ /V | > 6 m | 6.0/9 | | | "F" at time "0": 6.2*. Limit of acceptability: 6 | Hollender (1963) |
| | | | 70/ /V | > 3 m | 6.6/9 | | | | |
| | | | 100/ /V | < 3 m | 5.0/9 | | | | |
| Pears | FD | Vacuum: 27 inches | 40/ /V | < 3 m | 5.2/9 | | | "F" at time "0"" 5.6*. Limit of acceptability: 6 | Hollender (1963) |
| | | | 70/ /V | < 3 m | 5.6/9 | | | | |
| | | | 100/ /V | < 3 m | 5.0/9 | | | | |
| Pineapple | FD | Vacuum: 27 inches | 40/ /V | < 3 m | 5.0/9 | | | "F" at time "0": 5.6*. Limit of acceptability: 6 | |
| | | | 70/ /V | < 3 m | 5.4/9 | | | | |
| | | | 100/ /V | < 3 m | 5.6/9 | | | | |
| Prunes | FD | Vacuum: 27 inches | 40/ /V | < 3 m | 5.2/9 | | | "F" at time "0": 6.2*. Limit of acceptability: 6 | Hollender (1963) |
| | | | 70/ /V | 3 m | 6.0/9 | | | | |
| | | | 100/ /V | < 3 m | 5.6/9 | | | | |

* Storage at $40^{\circ}F$ for one month

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
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| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Raisins | Sun D | Regular raisins | 70/16.08/A | 600 d | | | | Darkening:<br>Ea. = 26 Kcal/mole regular raisins | Nury & Brekke (1963) |
| | | | 90/16.08/A | 95 d | | | | | |
| | | Golden raisins | 70/16.05/A | 500 d | | | | Ea. = 24 Kcal/mole golden raisins | |
| | | | 90/16.05/A | 80 d | | | | | |
| | | | | | | Absorbance | | | |
| | AD | | 70/16.1-16.5/A | 34 w (F) | | 0.46/0.30 | | Control: 32°F (on the vine-dried: OVD) $P_c$ 50 Flavor & color followed a similar pattern | Stafford & Guadagni (1977) |
| | | | 90/16.1-16.5/A | 8.8 w (F) | | 0.50/0.30 | | | |
| | OVD | | 70/16.1-16.5/A | 41 w (F) | | 0.18/0.0[illegible] | | | |
| | | | 90/16.1-16.5/A | 14 w (F) | | 0.25/0.0[illegible] | | | |
| | Sun D | | 70/16.1-16.5/A | 31-43 w (F) | | 0.50/0.30 | | | |
| | | | 90/16.1-16.5/A | 11-11.5 w (F) | | 0.62/0.30 | | | |



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|---|---|---|---|---|---|---|---|---|---|---|---|
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| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

# VEGETABLES

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Beets | AD | | 75/4.9/A | > 12 m (F) | 6.6/10 | | | "6" is considered minimum level of acceptability. | Continental Can Co. (1944) |
| | | | 75/4.9/N | > 12 m (F) | 6.7/10 | | | | |
| | | | 75/4.9/CO | > 12 m (F) | 6.8/10 | | | | |
| | | | 75/3.7/A | > 12 m (F) | 6.6/10 | | | | |
| | | | 75/3.7/N | > 12 m (F) | 6.8/10 | | | | |
| | | | 75/3.7/CO | > 12 m (F) | 6.9/10 | | | | |
| | | | 98/4.9/A | > 3 m (F) | 7.0/10 | | | | |
| | | | 98/4.9/N | > 3 m (F) | 7.3/10 | | | | |
| | | | 98/4.9/CO | ~ 6 m (F) | 6.0/10 | | | | |
| | | | 98/3.7/A | > 3 m (F) | 7.0/10 | | | | |
| | | | 98/3.7/N | > 3 m (F) | 7.1/10 | | | | |
| | | | 98/3.7/CO | ~ 6 m (F) | 6.0/10 | | | | |
| | | | 130/4.9/A | < 1 m (F) | 2.5/10 | | | | |
| | | | 130/4.9/N | < 1 m (F) | 3.2/10 | | | | |
| | | | 130/4.9/CO | < 1 m (F) | 4.3/10 | | | | |
| | | | 130/3.7/A | < 1 m (F) | 5.0/10 | | | | |
| | | | 130/3.7/N | < 1 m (F) | 5.0/10 | | | | |
| | | | 130/3.7/CO | < 1 m (F) | 5.0/10 | | | | |
| Cabbage | AD | $SO_2$:1,000 ppm | 120/6.6/N | 0.7 d (CO) | | | | Days required for presence of a low level of browning. | Legault, et al (1951) |
| | | | 120/3.4/N | 1.8 d (CO) | | | | | |
| | | | 120/2.1/N | 6.0 d (CO) | | | | | |
| | | | 120/3.4/A | 2.0 d (CO) | | | | | |
| | | | 109/6.6/N | 1.5 d (CO) | | | | | |
| | | | 109/3.4/N | 7.0 d (CO) | | | | | |
| | | | 109/2.1/N | 21 d (CO) | | | | | |
| | | | 109/3.4/A | 8 d (CO) | | | | | |
| | | | 100/6.6/N | 3.5 d (CO) | | | | | |
| | | | 100/3.4/N | 18 d (CO) | | | | | |
| | | | 100/2.1/N | 64 d (CO) | | | | | |
| | | | 100/3.4/A | 14 d (CO) | | | | | |
| | | | 75/6.6/N | 60 d (CO) | | | | | |
| | | | 75/3.4/N | 330 d (CO) | | | | | |
| | | | 75/2.4/N | > 725 d (CO) | | | | | |
| | | | 75/3.4/A | 280 d (CO) | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
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| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
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|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Texture | | |
| Cabbage | AD | + IPD | 120/0.4/N | > 60 d | > 60d | > 60d | > 60d | Days required for | Legault |
| | | - IPD | 120/3.1/N | 10 d (CO) | 14d | 10d | 14d | presence of a | et al |
| | | + IPD | 120/0.4/A | 42d | 42d | 42d | 42d | low level of | (1954) |
| | | - IPD | 120/3.1/A | 7 d (CO+F) | 7d | 7d | > 14d | browning. | |
| | | + IPD | 100/0.7/N | 357 d (F) | 357d | >525d | >525d | | |
| | | - IPD | 100/3.1/N | 84 d (CO+F) | 84d | 84d | >127d | | |
| | | + IPD | 100/0.7/A | 357 d (F) | 357d | >525d | >525d | 930 ppm $SO_2$ | |
| | | - IPD | 100/3.1/A | 84 d (CO+F) | 84d | 84d | >127d | | |
| | | + IPD | 75/1.2/N | >670 d | >670d | >670d | >670d | | |
| | | - IPD | 75/3.1/N | >670 d | >670d | >670d | >670d | | |
| | | + IPD | 75/1.2/A | >670 d | >670d | >670d | >670d | | |
| | | - IPD | 75/3.1/A | >670 d | >670d | >670d | >670d | | |
| | AD | | 75/4.0/A | < 1 m (F) | 4.3/10 | | | "6" is considered | Conti- |
| | | | 75/4.0/N | > 6 m (F) | 7.0/10 | | | minimum level of | nental |
| | | | 75/4.0/CO | >12 m (F) | 6.1/10 | | | acceptability. | Can Co. |
| | | | 75/2.9/A | > 6 m (F) | 6.3/10 | | | | (1944) |
| | | | 75/2.9/N | >12 m (F) | 6.5/10 | | | | |
| | | | 75/2.9/CO | >12 m (F) | 6.1/10 | | | | |
| | | | 98/4.0/A | < 1 m (F) | 5.3/10 | | | | |
| | | | 98/4.0/N | > 1 m (F) | 6.3/10 | | | | |
| | | | 98/4.0/CO | > 1 m (F) | 6.4/10 | | | | |
| | | | 98/2.9/A | > 1 m (F) | 6.6/10 | | | | |
| | | | 98/2.9/N | > 1 m (F) | 6.5/10 | | | | |
| | | | 98/2.9/CO | > 1 m (F) | 7.1/10 | | | | |
| | | | 130/4.0/A | < 1 m (F) | I | | | | |
| | | | 130/4.0/N | < 1 m (F) | N | | | | |
| | | | 130/4.0/CO | < 1 m (F) | E | | | | |
| | | | 130/2.9/A | < 1 m (F) | D | | | | |
| | | | 130/2.9/A | < 1 m (F) | I | | | | |
| | | | 130/2.9/CO | < 1 m (F) | B | | | | |
| | | | | | L | | | | |
| | | | | | E | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
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|---|---|---|---|---|---|---|---|---|---|
| Carrot | FD | | 68/ /A | 1 m (F) | | | | | Palmer, et al (1963) |
| | | 2% $O_2$ | 68/ /O | 3 m (F) | | | | | |
| | | 1% $O_2$ | 68/ /O | 6 m (F) | | | | | |
| | | 0.1% $O_2$ | 86/ /O | 6 m (F) | | | | | |
| | DD | | 0/5.0/N | >24 m | | | | | Stephen & McLemore (1969) |
| | | | 68/5.0/N | >24 m | | | | | |
| | | | 0/5.0/A | < 2 m | | | | | |
| | | | 68/5.0/A | < 2 m | | | Carotenoids | | |
| | AD | Blanched in tap water & dried | 68/1.0/A | < 6 m (F+CO) | | | 0.63 | Carotenoid content measured as OD at 450 nm after 1 year | Speck, et al (1977) |
| | | | 68/4.0/A | < 6 m (F+CO) | | | 0.55 | | |
| | | | 68/9.0/A | < 6 m (F+CO) | | | 0.41 | | |
| | | Soaked and blanched in NaCl solution and dried | 68/1.0/A | <18 m | | | 0.89 | Samples at 9% residual water were judged to be significantly lower in quality | |
| | | | 68/4.0/A | <18 m | | | 0.67 | | |
| | | | 68/9.0/A | <18 m | | | 0.53 | | |
| | | | | | | | Texture | | |
| | FD | Unblanched -25 lactose/10 NaCl | 73/ /A | > 6 w (F) | 7.2/9 | | 6.8/9 | Presence of an oxidative flavor of samples stored in air | Karel & Fink (1978) |
| | | Blanched -25 lactose/10 NaCl | 73/ /A | < 6 w (F) | 4.5/9 | | 6.4/9 | | |
| | | Unblanched, plain | 73/ /A | < 1 w (F) | 4.4/9 | | 5.0/9 | | |
| | | Blanched, plain | 73/ /A | < 6 w (F) | 3.1/9 | | 6.1/9 | Hedonic scale: 1-9. | |
| | FD | Unblanched -25 lactose/10 NaCl | 73/ /V | <18 w (T) | 5.1/9 | | 4.7/9 | All samples stored under vacuum, developed an oxidized flavor | |
| | | Blanched -25 lactose/10 NaCl | 73/ /V | <18 w (F) | 5.8/9 | | 5.2/9 | | |
| | | Unblanched, plain | 73/ /V | <18 w (F) | 5.3/9 | | 6.1/9 | Hedonic scale: 1-9 | |
| | | Blanched, plain | 73/ /V | <18 w (F) | 5.4/9 | | 6.8/9 | | |
| | AD | | 99/ /N | ∿ 2 m (F) | | 6.3/8 | 5.3/8 | Culinary test score: 1-8. 5 was assumed to be limit of acceptability. | Gooding & Ducworth (1957) |
| | | | 131/ /N | ∿ 2 d (F) | | 6.1/8 | 5.5/8 | | |

| | | | | | | | | | | | |
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| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Odor | | |
| Carrot | FD | "Zero oxygen" | 100/1.5/H-N | 12 m (F) | >12 m | >12 m | >12 m | +$H_2$ & catalyst | Bishov, |
| | | 0.5% oxygen | 100/1.5/O | ~ 9 m (OD) | >12 m | >12 m | > 9 m | vacuum closing | et al. |
| | | 1.0% oxygen | 100/1.5/O | ~ 2 m | 2 m | 2 m | 2 m | nitrogen flush | (1971) |
| | | 2.2% oxygen | 100/1.5/O | 0.5 m (F+OD) | 2 w | 2 m | 2 w | $O_2 + N_2$ F, CO, OD given in time to detect appreciable changes | |
| | AD | | 75/5.6/A | > 3 m | 6.7/10 | | | "6" is considered | (Conti- |
| | | | 75/5.6/N | >12 m | 6.1/10 | | | the min. level of | nental |
| | | | 75/5.6/CO | >12 m | 6.4/10 | | | acceptability. | Can Co. |
| | | | 75/4.6/A | ~ 3 m | 6.0/10 | | | All samples | (1944) |
| | | | 75/4.6/N | >12 m | 6.3/10 | | | in air had straw | |
| | | | 75/4.6/CO | >12 m | 6.2/10 | | | or haylike odor. | |
| | | | 98/5.6/A | < 1 m (F) | 5.5/10 | | | | |
| | | | 98/5.6/N | ~ 3 m (F) | 6.0/10 | | | | |
| | | | 98/5.6/CO | > 1 m (F) | 7.1/10 | | | | |
| | | | 98/4.6/A | > 1 m (F) | 6.8/10 | | | | |
| | | | 98/4.6/N | > 3 m (F) | 7.0/10 | | | | |
| | | | 98/4.6/CO | > 3 m (F) | 6.8/10 | | | | |
| | | | 130/5.6/A | < 1 m (F) | INEDIBLE | | | | |
| | | | 130/5.6/N | < 1 m (F) | | | | | |
| | | | 130/5.6/CO | < 1 m (F) | | | | | |
| | | | 130/4.6/A | < 1 m (F) | | | | | |
| | | | 130/4.6/N | < 1 m (F) | | | | | |
| | | | 130/4.6/CO | < 1 m (F) | | | | | |
| | AD | | 77/ /A | ~ 2 m (F) | ~6.0/8.0 | ~ 6.8/8.0 | | "6" was assumed to be minimum level of acceptability | Meijer, (1968) |



| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Texture | | |
| Carrot | AD | 660 $SO_2$ + IPD | 120/5.0/N | 41 d (CO+F) | 41 d | 41 d | > 48 d | F, CO, & texture are given in days required to obtain the minimum level of acceptability. $SO_2$ concentrations in ppm. | Legault, et al (1954) |
| | | 660 $SO_2$ - IPD | 120/5.0/N | 13 d (CO) | 20 d | 13 d | 34 d | | |
| | | 0 $SO_2$ + IPD | 120/5.0/N | 20 d (F) | 20 d | 27 d | 34 d | | |
| | | 0 $SO_2$ - IPD | 120/5.0/N | 7 d (F) | 7 d | 27 d | 34 d | | |
| | | 660 $SO_2$ + IPD | 100/5.0/N | 184 d (F) | 184 d | 247 d | >275 d | | |
| | | 660 $SO_2$ - IPD | 100/5.0/N | 156 d (CO) | >184 d | 156 d | >184 d | | |
| | | 660 $SO_2$ + IPD | 100/5.0/A | 0 d (CO) | 100 d | 0 d | >184 d | | |
| | | 660 $SO_2$ - IPD | 100/5.0/A | 0 d (CO) | 100 d | 0 d | >184 d | | |
| | | 0 $SO_2$ + IPD | 100/5.0/N | 121 d (CO+F) | 121 d | 121 d | >175 d | | |
| | | 0 $SO_2$ - IPD | 100/5.0/N | 27 d (CO) | 121 d | 27 d | 156 d | | |
| | | 0 $SO_2$ + IPD | 100/5.0/A | 0 d (CO) | 121 d | 0 d | >175 d | | |
| | | 0 $SO_2$ - IPD | 100/5.0/A | 0 d (CO+F) | 0 d | 0 d | 121 d | | |
| | | 660 $SO_2$ + IPD | 75/5.0/N | >625 d | >625 d | >625 d | >625 d | | |
| | | 660 $SO_2$ - IPD | 75/5.0/N | >625 d | >625 d | >625 d | >625 d | | |
| | | 660 $SO_2$ + IPD | 75/5.0/A | 163 d (CO+F) | 163 d | 163 d | >625 d | | |
| | | 660 $SO_2$ - IPD | 75/5.0/A | 163 d (CO+F) | 163 d | 163 d | 457 d | | |
| | | 0 $SO_2$ + IPD | 75/5.0/N | >457 d | >457 d | >457 d | >457 d | | |
| | | 0 $SO_2$ - IPD | 75/5.0/N | >457 d | >457 d | >457 d | >457 d | | |
| | | 0 $SO_2$ + IPD | 75/5.0/A | 107 d (CO) | 163 d | 107 d | >457 d | | |
| | | 0 $SO_2$ - IPD | 75/5.0/A | 20 d (CO) | 107 d | 20 d | >457 d | | |
| | AD | | 120/7.4/N | 14 d | | | | 1920 ppm $SO_2$ for all samples. Quality given as days required to obtain a low level of browning. | Legault et al (1951) |
| | | | 120/5.8/N | 17 d | | | | | |
| | | | 120/5.1/N | 18 d | | | | | |
| | | | 120/5.8/A | 16 d | | | | | |
| | | | 120/7.4/N | 38 d | | | | | |
| | | | 110/5.8/N | 40 d | | | | | |
| | | | 110/5.1/N | 48 d | | | | | |
| | | | 110/5.8/A | 38 d | | | | | |
| | | | 100/7.4/N | 100 d | | | | | |
| | | | 100/5.8/N | 120 d | | | | | |
| | | | 100/5.1/N | 170 d | | | | | |
| | | | 100/5.8/A | 130 d | | | | | |
| | | | 75/7.4/N | >855 d | | | | | |
| | | | 75/5.8/N | >855 d | | | | | |
| | | | 75/5.1/N | >855 d | | | | | |
| | | | 75/5.8/A | >855 d | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLORS | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Cauliflower | AD | | 77/ /A | < 1 m (CO) | ~6.7/8 | ~5.9/8 | | "6" was assumed to be the min. level of acceptability. | Meijer (1968) |
| Green beans | FD | "Zero oxygen" | 100/1.5/H-N | 12 m (F) | | | | | Bishov et al (1971) |
| | | 2% oxygen | 100/1.5/O | 5 m (F) | | | | | |
| | | | | | | | Texture | | |
| | FD | Var. seminole | 75/5-6/ A | > 6 m (7.2) | 7.0 | 6.7 | 8.5 | Samples placed in metal containers. Final score is given: (F)0.5 + (O)0.3 + (T) 0.2. "6" was assumed to be the min. level of acceptability | Foda et al (1967) |
| | | Var. ideal | 75/5-6/ A | > 7 m (8.4) | 8.2 | 9.0 | 8.0 | | |
| | | Var. contender | 75/5-6/ A | > 6 m (8.2) | 7.8 | 8.3 | 9.0 | | |
| | | Var. Montcalme | 75/5-6/ A | > 6 m (9.8) | 8.2 | 9.3 | 10.0 | | |
| | AD | Var. seminole | 75/5-6/ A | < 6 m (4.8) | 4.6 | 3.3 | 7.5 | | |
| | | Var. ideal | 75/5-6/ A | > 6 m (6.1) | 6.4 | 4.0 | 8.5 | | |
| | | Var. contender | 75/5-6/ A | < 6 m (5.2) | 5.0 | 3.3 | 8.5 | | |
| | | Var. Montcalme | 75/5-6/ A | ~ 6 m (6.0) | 6.2 | 5.0 | 7.0 | | |
| | AD | Sliced | 77/ /A | > 8 m | ~7.1/8.0 | ~7.0/8 | | "6" was assumed to be min. level of acceptability | Meijer (1968) |
| Kale (curly) | AD | | 77/ /A | < 8 m (F) | ~5.7/8.0 | ~7.6/8 | | "6" was assumed to be min. level of acceptability | Meijer (1968) |
| Leek | AD | | 77/ /A | ~ 6 m (F) | ~6.0/8.0 | ~6.9/8 | | "6" was assumed to be minimum level of acceptability. | Meijer (1968) |
| Mushrooms | AD | Drying T: 110° F | 73/6.5/A | > 7 m | 3.65 | | | "5" better than freshly dried standard," 4 same as std.," 1 definitely off flavor. 3: assumed level of acceptability. Mushrooms dried to moisture below 4% are tough on reconstitution & poor in flavor | Komanowsky et al (1970) |
| | | 140° F | 73/6.5/A | > 7 m | 3.48 | | | | |
| | | 195° F | 73/6.5/A | > 7 m | 3.26 | | | | |
| | | 110° F | 73/12.0/A | > 2 m | 3.17 | | | | |
| | | 140° F | 73/12.0/A | < 2 m | 2.96 | | | | |
| | | 198° F | 73/12.0/A | < 2 m | 2.52 | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Onions | AD | | 75/3.5/A | > 9 m (F) | 6.6/10 | | | "6" is considered minimum level of acceptability | Continental Can Co. (1944) |
| | | | 75/3.5/N | >12 m (F) | 6.8/10 | | | | |
| | | | 75/3.5/CO | >12 m (F) | 6.5/10 | | | | |
| | | | 98/3.5/A | > 1 m (F) | 7.2/10 | | | | |
| | | | 98/3.5/N | > 1 m (F) | 7.2/10 | | | | |
| | | | 98/3.5/CO | > 1 m (F) | 7.3/10 | | | | |
| | | | 130/3.5/A | < 1 m (F) | Inedible | | | | |
| | | | 130/3.5/N | < 1 m (F) | " | | | | |
| | | | 130/3.5/CO | < 1 m (F) | " | | | | |
| | | | | | | | Texture | | |
| | AD | + IPD | 120/2.7/N | 22 d (CO+F) | 22 d | 22 d | > 43 d | F, CO & texture are given in days required to obtain the min. level of acceptability. | Legault et al (1954) |
| | | - IPD | 120/3.5/N | 10 d (CO) | > 15 d | 10 d | > 15 d | | |
| | | + IPD | 120/2.7/A | 22 d (CO+F) | 22 d | 22 d | > 43 d | | |
| | | - IPD | 120/3.5/A | 6 d (CO+F) | 6 d | 6 d | > 15 d | | |
| | | + IPD | 100/2.7/N | >486 d (CO) | >486 d | >486 d | >486 d | | |
| | | - IPD | 100/3.5/N | 88 d (CO+F) | 88 d | 88 d | >189 d | | |
| | | + IPD | 100/2.7/A | 366 d (CO) | >486 d | 366 d | >486 d | | |
| | | - IPD | 100/3.5/A | 88 d (CO+F) | 88 d | 88 d | >189 d | | |
| | | + IPD | 75/2.7/N | >673 d | >673 d | >673 d | >673 d | | |
| | | - IPD | 75/3.5/N | >673 d | >673 d | >673 d | >673 d | | |
| | | + IPD | 75/2.7/A | >673 d | >673 d | >673 d | >673 d | | |
| | | - IPD | 75/3.5/A | >673 d | >673 d | >673 d | >673 d | | |
| Peas (green) | FD | "Zero oxygen" | 100/1.5/H-N | 12 m | | | | | Bishov, et al (1967) |
| | | 2.0% oxygen | 100/1.5/O | 6 m | | | | | |
| Potatoes (white) | AD | | 75/7.0/A | > 6 m | 6.2/10 | | | "6" is considered the min. level of acceptability. | Continental Can Co. (1944) |
| | | | 75/7.0/N | > 6 m | 7.4/10 | | | | |
| | | | 75/7.0/CO | >12 m | 6.2/10 | | | | |
| | | | 98/7.0/A | > 1 m | 7.5/10 | | | | |
| | | | 98/7.0/N | > 1 m | 7.2/10 | | | | |
| | | | 98/7.0/CO | > 1 m | 6.4/10 | | | | |
| | | | 130/7.0/A | < 2 w (F) | 4.7/10 | | | | |
| | | | 130/7.0/N | < 2 w (F) | 4.7/10 | | | | |
| | | | 130/7.0/CO | < 2 w (F) | 4.7/10 | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions $T(^{o}F)$/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Potatoes (cont'd) | | | | | | | Texture | | |
| | AD | 400 $SO_2$ +IPD | 120/4.8/N | 50 d | 50 d | 50 d | 50 d | F, CO, & T are given in days required to obtain the min. level of acceptability. $SO_2$ concentration in ppm. | Legault, et al (1954) |
| | | 400 $SO_2$ -IPD | 120/4.8/N | 15 d | 15 d | 15 d | 15 d | | |
| | | 400 $SO_2$ +IPD | 120/4.8/A | 50 d (CO+F) | 50 d | 50 d | >63 d | | |
| | | 400 $SO_2$ -IPD | 120/4.8/A | 6 d (T) | 12 d | 12 d | 6 d | | |
| | | 0 $SO_2$ +IPD | 120/4.8/N | 11 d (CO+F) | 11 d | 11 d | 41 d | | |
| | | 0 $SO_2$ -IPD | 120/4.8/N | 4 d (CO+F) | 4 d | 4 d | 11 d | | |
| | | 0 $SO_2$ +IPD | 120/4.8/A | 11 d (CO) | 16 d | 11 d | 23 d | | |
| | | 0 $SO_2$ -IPD | 120/4.8/A | 4 d (CO+F) | 4 d | 4 d | 11 d | | |
| | | 400 $SO_2$ +IPD | 100/4.8/N | 482 d (CO) | 531 d | 482 d | >623 d | | |
| | | 400 $SO_2$ -IPD | 100/4.8/N | 134 d (CO) | 174 d | 134 d | 174 d | | |
| | | 400 $SO_2$ +IPD | 100/4.8/A | 328 d (F) | 328 d | 531 d | >623 d | | |
| | | 400 $SO_2$ -IPD | 100/4.8/A | 134 d (CO+F) | 134 d | 134 d | >202 d | | |
| | | 0 $SO_2$ +IPD | 100/4.8/N | 203 d (F) | 203 d | 266 d | 322 d | | |
| | | 0 $SO_2$ -IPD | 100/4.8/N | 22 d (CO) | 52 d | 22 d | 107 d | | |
| | | 0 $SO_2$ +IPD | 100/4.8/A | 266 d (CO+F) | 266 d | 266 d | 322 d | | |
| | | 0 $SO_2$ -IPD | 100/4.8/A | 22 d (CO) | 79 d | 22 d | 107 d | | |
| | | 400 $SO_2$ +IPD | 75/4.8/N | >643 d | >643 d | >643 d | >643 d | | |
| | | 400 $SO_2$ -IPD | 75/4.8/N | >643 d | >643 d | >643 d | >643 d | | |
| | | 400 $SO_2$ +IPD | 75/4.8/A | >643 d | >643 d | >643 d | >643 d | | |
| | | 400 $SO_2$ -IPD | 75/4.8/A | >643 d | >643 d | >643 d | >643 d | | |
| | | 0 $SO_2$ +IPD | 75/4.8/N | >644 d | >644 d | >644 d | >644 d | | |
| | | 0 $SO_2$ -IPD | 75/4.8/N | >644 d | >644 d | >644 d | >644 d | | |
| | | 0 $SO_2$ +IPD | 75/4.8/A | >644 d | >644 d | >644 d | >644 d | | |
| | | 0 $SO_2$ -IPD | 75/4.8/A | >644 d | >644 d | >644 d | >644 d | | |
| | AD | | 120/8.4/N | 11 d (CO) | | | | Quality given as days required for formation of a medium degree of browning. 330 ppm $SO_2$ given for all of these samples | Legault, et al (1951) |
| | | | 120/7.1/N | 15 d (CO) | | | | | |
| | | | 120/5.0/N | 32 d (CO) | | | | | |
| | | | 120/7.1/A | 14 d (CO) | | | | | |
| | | | 110/8.4/N | 27 d (CO) | | | | | |
| | | | 110/7.1/N | 44 d (CO) | | | | | |
| | | | 110/5.0/N | > 61 d (CO) | | | | | |
| | | | 110/7.1/A | 40 d (CO) | | | | | |
| | | | 100/8.4/N | 84 d (CO) | | | | | |
| | | | 100/7.1/N | 140 d (CO) | | | | | |
| | | | 100/5.0/N | >365 d (CO) | | | | | |
| | | | 100/7.1/A | 125 d (CO) | | | | | |
| | | | 90/8.4/N | 200 d (CO) | | | | | |
| | | | 90/7.1/N | 320 d (CO) | | | | | |
| | | | 90/5.0/N | >600 d (CO) | | | | | |
| | | | 90/7.1/A | 230 d (CO) | | | | | |
| | | | 75/8.4/N | 650 d (CO) | | | | | |
| | | | 75/7.1/N | >820 d (CO) | | | | | |
| | | | 75/5.0/N | >690 d (CO) | | | | | |
| | | | 75/7.1/A | >690 d (CO) | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| PSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T($^{o}$F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Potatoes (cont'd) | FD | "Zero oxygen" | 100/1.5/H-N | 12 m (F) | | | | + $H_2$ & catalyst | Bishov, |
| | | 2.0% oxygen | 100/1.5/O | 8 m (F) | | | | Low sugar Maine | et al |
| | | | | | | | | Kennebec potat- | (1971) |
| | EP | | 73/5.0/N | > 12 m (F) | 3.83/7 | | | oes | |
| | | +35 ppm BHA | 73/5.0/A | > 10 m (F) | 3.73/7 | | | Flavor: "4" = | Konstance |
| | | + 50 ppm BHA | 73/5.0/A | < 8 m (F) | 3.42/7 | | | same as standard | et al |
| | | + 70 ppm BHA | 73/5.0/A | > 10 m (F) | 3.87/7 | | | "7" very much | (1978) |
| | | | | | | | | better than std. | |
| | | BHA + BHT | 73/5.0/A | > 12 m (F) | 3.75/7 | | | PG=propyl galate | |
| | | BHA + PG | 73/5.0/A | < 5 m (F) | 3.36/7 | | | AP=ascorbyl palmitate | |
| | | BHA + PG + AP | 73/5.0/A | < 5 m (F) | 2.86/7 | | | BHA=butylated hydroxyanisole | |
| | | | | | | | | BHT=butylated hydroxytoluene | |
| | | (pouch) | 73/5.0/N | > 9 m (F) | 4.00/7 | | | + scavenger | |
| | | (can) | 100/5.0/N | > 12 m (F) | 3.77/7 | | | + scavenger | |
| | | (pouch) | 100/5.0/N | > 12 m (F) | 3.75/7 | | | + scavenger | |
| | EP | | 0/3-4/N | > 12 m (F) | 3.87/4.0 | | | High sugar Maine | Sullivan |
| | | | 73/3-4/N | > 12 m (F) | 3.87/4.0 | | | Kennebec potatoes | et al |
| | | | 73/3-4/A | < 3 m (F) | 3.44/4.0 | | | Flavor "4" same as | (1974) |
| | | | 100/3-4/N | < 2 m (F) | 3.40/4.0 | | | standard. "6" much | |
| | | | | | | | | better than standard. | |
| | | | 0/3-4/N | > 12 m (F) | 4.07/4.09 | | | High sugar Maine | |
| | | | 73/3-4/N | > 12 m (F) | 3.87/4.09 | | | Russet Burbank | |
| | | | 73/3-4/A | < 3 m (F) | 3.25/4.09 | | | potatoes. | |
| | | | 100/3-4/N | < 1 m (F) | 3.50/4.09 | | | | |
| | | | 0/3-4/N | > 12 m (F) | 3.92/ | | | Low sugar Maine | |
| | | | 73/3-4/N | > 12 m (F) | 3.62/ | | | Kennebec potatoes | |
| | | | 73/3-4/A | < 1 m (F) | 3.19/ | | | | |
| | | | 100/3-4/N | > 6 m (F) | 4.00/ | | | | |
| | | | 0/3-4/N | > 6 m (F) | 3.82/ | | | Low sugar Russet | |
| | | | 73/3-4/N | > 6 m (F) | 3.80/ | | | Burbank potatoes | |
| | | | 73/3-4/A | < 3 m (F) | 3.07/ | | | Flavor score at time t/ | |
| | | | 100/3-4/N | > 6 m (F) | 4.06/ | | | Flavor score at time 0 | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

Vegetables (continued)

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Potatoes (cont'd) | DD | Under-dried | 73/7.02/A | <12 m (F) | 3.9/4.9 | | | 8-point rating scale "5" std. Flavor score at time t/ flavor score at time 0 | Sapers, et al (1974) |
| | | Normally-dried | 73/4.69/A | <12 m (F) | 3.9/4.7 | | | | |
| | | Over-dried | 73/3.12/A | <12 m (F) | 3.3/4.0 | | | | |
| | | Normally-dried | 73/6.98/A | <12 m (F) | 3.6/4.7 | | | | |
| | | Normally-dried | 73/4.69/A | <12 m (F) | 3.8/4.7 | | | | |
| | | Normally-dried | 73/3.50/A | <12 m (F) | 3.7/4.7 | | | | |
| | DD | | 98.6/ 4/N | 212 d (CO+F) | | | | $SO_2$: 200 ppm for for all samples | Stephenson, et al (1958) |
| | | | 98.6/ 6/N | 152 d (CO) | | | | | |
| | | | 98.6/ 8/N | 75 d (CO) | | | | | |
| | | | 98.6/10/N | 75 d (CO) | | | | | |
| | | | | | | OD X 1000 | | | |
| | | + 5 ppm BHA | 75/10/A | <212 d (odor) | >777 d | 44.6/43.5 | | CO: Readings of OD extracted color x 1000 after 309 days sample/control' Control stored in air. Aroma in $N_2$ packs was preferred. Rancidity was not observed in any sample within 309 days (except for control). No texture changes were detected in any sample. Preference: N + BHA >N > BHA > A Flavor given as days to detect rancidity. | |
| | | " " " | 75/ 8/A | <212 d (odor) | >777 d | 41.8/44.6 | | | |
| | | " " " | 75/ 6/A | <212 d (odor) | >777 d | 37.9/43.2 | | | |
| | | " " " | 75/ 4/A | <212 d (odor) | 309 d | 44.6/52.0 | | | |
| | | " " " | | | | | | | |
| | | | 75/10/N | <212 d (odor) | 489 d | 46.0/43.5 | | | |
| | | | 75/ 8/N | <212 d (odor) | 489 d | 49.3/44.6 | | | |
| | | | 75/ 6/N | <212 d (odor) | 489 d | 55.0/43.2 | | | |
| | | | 75/ 4/N | <212 d (odor) | 309 d | 52.0/52.0 | | | |
| | | + 5 ppm BHA | 75/10/N | <212 d (odor) | >777 d | 40.3/43.5 | | | |
| | | " " " | 75/ 8/N | <212 d (odor) | >777 d | 48.9/44.6 | | | |
| | | " " " | 75/ 6/N | <212 d (odor) | >777 d | 36.9/43.2 | | | |
| | | " " " | 75/ 4/N | <212 d (odor) | <777 d | 50.5/52.0 | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

Vegetables (continued)

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | OD x 1000 | CO after 777 days/0 days | |
| Potatoes (cont'd) | | | 40/10/A | >777 d | OK | | 60.0/69 | Rancidity free | |
| | | | 40/10/N | >777 d | OK | | 58.0/69 | Gassy aroma, rancidity free | |
| | | + 5 ppm BHA | 40/10/A | >777 d | OK | | 52.5/69 | " " " " | |
| | | + 5 ppm BHA | 40/10/N | >777 d | OK | | 52.5/69 | " " " " | |
| | | | 40/ 8/A | <777 d | Off flavor | | 49.4/69 | Rancid | |
| | | | 40/ 8/N | <777 d | | | 59.5/69 | Borderline in rancidity | |
| | | + 5 ppm BHA | 40/ 8/A | >777 d | OK | | 52.5/69 | | |
| | | + 5 ppm BHA | 40/ 8/N | >777 d | OK | | 51.5/69 | Rancidity free | |
| | | | 40/ 6/A | <777 d | Off flavor | | 59.5/69 | Rancid | |
| | | | 40/ 6/N | <777 d | | | 60.5/69 | Borderline in rancidity | |
| | | + 5 ppm BHA | 40/ 6/A | >777 d | OK | | 60.5/69 | Bland aroma | |
| | | + 5 ppm BHA | 40/ 6/N | >777 d | OK | | 73.0/69 | Bland aroma, rancidity free | |
| | | | 40/ 4/A | <777 d | | | 52.5/69 | Rancid | |
| | | | 40/ 4/N | >777 d | OK | | 52.5/69 | Rancidity free | |
| | | + 5 ppm BHA | 40/ 4/A | >777 d | OK | | 52.5/69 | Bland aroma | |
| | | + 5 ppm BHA | 40/ 4/N | >777 d | OK | | 50.5/69 | Bland aroma, rancidity free | |
| | | | | | Acceptability | | | | |
| | DD | Tenox IV | 70/5.8/N | > 11 m | 88% | | | | Drazga, et al (1964) |
| | | | 70/6.0/N | > 11 m | 82% | | | | |
| | | Tenox IV | 70/5.8/A | ~ 11 m | 63% | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Rutabagas | AD | | 75/3.8/A | > 3 m (F) | 6.2/10 | | | "6" is considered the min. level of acceptability. | Continental Can Co. (1944) |
| | | | 75/3.8/N | >12 m (F) | 6.7/10 | | | | |
| | | | 75/3.8/CO | >12 m (F) | 6.8/10 | | | | |
| | | | 98/3.8/A | > 3 m (F) | 6.4/10 | | | | |
| | | | 98/3.8/N | > 9 m (F) | 6.3/10 | | | | |
| | | | 98/3.8/CO | > 6 m (F) | 6.6/10 | | | | |
| | | | 130/3.8/A | < 2 w (F) | 5.7/10 | | | | |
| | | | 130/3.8/N | < 2 w (F) | 5.5/10 | | | | |
| | | | 130/3.8/CO | ∿ 2 w (F) | 6.0/10 | | | | |
| Spinach | FD | "Zero oxygen" | 100/1.5/H-N | 12 m (F) | | | | Hydrogen & catalyst. | Bishov, et al. (1971) |
| | | 2% oxygen | 100/1.5/O | 3 w (F) | | | | | |
| Sweet potatoes | FD | "Zero oxygen" | 100/1.5/H-N | 12 m (F) | | | | Diced | Bishov, et al (1971) |
| | | 2% oxygen | 100/1.5/O | 0.5 m (F) | | | | | |
| | | | | | | | Texture | | |
| | AD | + IPD | 120/2.9/A | 22 d (CO) | 64 d | 22 d | >76 d | F, CO, & texture are given in days required to obtain the min. level of acceptability. Moisture given for these samples is final moisture content. | Legault, et al. (1954) |
| | | - IPD | 120/6.9/A | 49 d (F+CO) | 49 d | 49 d | 64 d | | |
| | | + IPD | 100/2.9/N | >557 d | >557 d | >557 d | >557 d | | |
| | | - IPD | 100/6.9/N | >557 d | >557 d | >557 d | >557 d | | |
| | | + IPD | 100/2.9/A | 36 d (CO) | 49 d | 36 d | >151 d | | |
| | | - IPD | 100/6.9/A | 89 d (F+CO) | 89 d | 89 d | >151 d | | |
| | | + IPD | 75/3.1/N | 445 d (F) | 445 d | >557 d | >557 d | | |
| | | - IPD | 75/6.9/N | 445 d (F) | 445 d | >557 d | >557 d | | |
| | | + IPD | 75/3.1/A | 9 d (F+CO) | 9 d | 9 d | >407 d | | |
| | | - IPD | 75/6.9/A | 165 d (F+CO) | 165 d | 165 d | >407 d | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking | | |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color | | |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor | | |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor | | |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture | | |

Vegetables (continued)

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability [illegible] at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Tomato | DD | | 75-80/1.6/A | > 3 m | 6.1/10 | | | "6" is considered min. level of acceptability. | Continental Can Co. (1944) |
| | | | 75-80/1.6/N | ∼12 m | 6.0/10 | | | | |
| | | | 75-80/1.6/CO | >12 m | 6.8/10 | | | | |
| | | | 98/1.6/A | > 6 m | 6.4/10 | | | | |
| | | | 98/1.6/N | > 9 m | 6.3/10 | | | | |
| | | | 98/1.6/CO | > 9 m | 6.4/10 | | | | |
| | | | 130/1.6/A | < 1 m | - - - | | | | |
| | | | 130/1.6/N | ∼ 1 m | 6.0/10 | | | | |
| | | | 130/1.6/CO | ∼ 1 m | 6.0/10 | | | | |
| Turnip | AD | | 77/ /A | ∼ 7 m | ∼6.0/8 | ∼6.1/8 | | | Meijer (1968) |
| Yam (white) | DD | | 70/3.5/A | >90 d | 7.7/9 | 1.6 | | CO given as (ΔE): difference between samples color & freshly dried yam flakes' color. "6" was assumed min. level of acceptability of F . | Onayemi and Potter (1974) |
| | | | 85/3.5/A | <90 d | 5.8/9 | 1.5 | | | |
| | | | 100/3.5/A | <90 d | 5.2/9 | 2.3 | | | |
| | | | 70/5.8/A | >90 d | 6.5/9 | 2.2 | | | |
| | | | 85/5.8/A | <60 d | 5.4/9 | 2.6 | | | |
| | | | 100/5.8/A | | | | | | |
| | | | 70/7.8/A | >90 d | 7.9/9 | 3.2 | | | |
| | | | 85/7.8/A | >90 d | 7.6/9 | 3.1 | | | |
| | | | 100/7.8/A | >90 d | 6.3/9 | 3.3 | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking | | |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color | | |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor | | |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor | | |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture | | |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | AROMA | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| **(Meat & Meat Substitutes)** | | | | | | | | | |
| Bacon with applesauce | FD | Vacuum: 27 in. | 40/ /V | < 3 m | 5.9/9 | | | "F" at time "0": 6.08. Limit of acceptability: 6 | Hollender (1963) (1) |
| | | | 70/ /V | 6 m | 6.0/9 | | | | |
| | | | 100/ /V | < 3 m | 5.9/9 | | | | |
| Beef hash | FD | Vacuum: 27 in. | 40/ /V | > 6 m | 6.3/9 | | | "F" at time "0": 6.10. Limit of acceptability: 6 | (1) |
| | | | 70/ /V | > 6 m | 6.3/9 | | | | |
| | | | 100/ /V | > 6 m | 6.0/9 | | | | |
| Beef hash | FD | Vacuum: 30 in. | 100/1-2/V | > 12 w | 6.3/9 | | | "F" at time "0": 6.2. Limit of acceptability: 6 | Tuomy et al (1969) (2) |
| | | 28 in. | 100/1-2/V | > 4 w | 6.1/9 | | | | |
| | | 26 in. | 100/1-2/V | > 4 w | 6.3/9 | | | | |
| | | 24 in. | 100/1-2/V | > 2 w | 6.2/9 | | | | |
| | | 22 in. | 100/1-2/V | < 2 w | 5.7/9 | | | | |
| | | 20 in. | 100/1-2/V | < 2 w | 5.5/9 | | | | |
| | | 0 in. | 100/1-2/A | < 2 w | 5.1/9 | | | | |
| Beef pot roast | FD | Vacuum: 27 in. | 40/ /V | > 6 m | 6.9/9 | | | "F" at time "0": 6.5. Limit of acceptability: 6 | (1) |
| | | | 70/ /V | > 6 m | 6.0/9 | | | | |
| | | | 100/ /V | > 6 m | 6.6/9 | | Texture | | |
| Beef stew | FD | Vacuum: 30 in. | 100/1-2/V | > 24 w | 6.6/9 | 6.2/9 | 6.3/9 | "F" at time "0": 6.5. Odor at time "0"" 6.4. Texture at time "0": 6.1. Limit of acceptability: 6 (F) | Tuomy, et al (1968) |
| | | 28 in. | 100/1-2/V | > 24 w | 6.3/9 | 6.1/9 | 5.9/9 | | |
| | | 26 in. | 100/1-2/V | > 24 w | 6.2/9 | 5.9/9 | 5.6/9 | | |
| | | 24 in. | 100/1-2/V | > 2 w | 6.6/9 | 6.3/9 | 5.3/9 | | |
| | | 22 in. | 100/1-2/V | > 2 w | 6.4/9 | 6.4/9 | 5.7/9 | | |
| | | 20 in. | 100/1-2/V | < 2 w | 5.7/9 | 5.9/9 | 5.1/9 | | |
| | | 0 in. | 100/1-2/A | < 2 w | 4.5/9 | 5.9/9 | 5.1/9 | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | AROMA | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| (continued) | | | | | | | | | |
| Beef with gravy | FD | Vacuum: 27 in. | 40/ /V | > 6 m | 6.5/9 | | | "F" at time "0": 6.44. Limit of acceptability: 6. | (1) |
| | | | 70/ /V | > 6 m | 6.8/9 | | | | |
| | | | 100/ /V | 6 m | 6.0/9 | | | | |
| Beef with rice | FD | Vacuum: 30 in. | 100/1-2/V | ∿24 w | 5.9/9 | | | "F" at time "0": 6.8. Limit of acceptability: 6 | (2) |
| | | 28 in. | 100/1-2/V | >24 w | 6.4/9 | | | | |
| | | 26 in. | 100/1-2/V | >24 w | 6.1/9 | | | | |
| | | 24 in. | 100/1-2/V | >24 w | 6.3/9 | | | | |
| | | 22 in. | 100/1-2/V | ∿24 w | 5.9/9 | | | | |
| | | 20 in. | 100/1-2/V | ∿24 w | 5.8/9 | | | | |
| | | 0 in. | 100/1-2/A | ∿ 2 w | 5.8/9 | | | | |
| Beef with vegetables | FD | Vacuum: 27 in. | 40/ /V | > 6 m | 6.1/9 | | | "F" at time "0": 6.35. Limit of acceptability: 6 | (1) |
| | | | 70/ /V | 3 m | 6.0/9 | | | | |
| | | | 100/ /V | 3 m | 6.0/9 | | | | |
| Chicken and rice | FD | Vacuum: 30 in. | 100/1-2/V | >24 w | 6.3/9 | | | "F" at time "0": 6.7. Limit of acceptability: 6. | (2) |
| | | 28 in. | 100/1-2/V | >24 w | 6.2/9 | | | | |
| | | 26 in. | 100/1-2/V | >24 w | 6.1/9 | | | | |
| | | 24 in. | 100/1-2/V | ∿24 w | 5.8/9 | | | | |
| | | 22 in. | 100/1-2/V | >24 w | 6.2/9 | | | | |
| | | 20 in. | 100/1-2/V | >24 w | 6.1/9 | | | | |
| | | 0 in. | 100/1-2/A | < 2 w | 5.4/9 | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | AROMA | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| (continued) | | | | | | | | | |
| Chicken stew | FD | Vacuum: 30 in. | 100/1-2/V | >24 w | 6.0/9 | 6.5/9 | 5.3/9 | "F" at time "0": 6.7. Odor at time "0": 7.2. Texture at time "0": 5.1. Limit of acceptability 6 (F) | Tuomy et al. (1968) |
| | | 28 in. | 100/1-2/V | > 4 w | 6.5/9 | 6.8/9 | 5.4/9 | | |
| | | 26 in. | 100/1-2/V | > 4 w | 6.4/9 | 6.7/9 | 5.6/9 | | |
| | | 24 in. | 100/1-2/V | < 2 w | 5.7/9 | 6.7/9 | 5.0/9 | | |
| | | 22 in. | 100/1-2/V | > 4 w | 6.3/9 | 5.8/9 | 6.3/9 | | |
| | | 20 in. | 100/1-2/V | > 4 w | 6.1/9 | 6.7/9 | 5.5/9 | | |
| | | 0 in. | 100/1-2/A | < 2 w | 4.9/9 | 6.2/9 | 5.1/9 | | |
| Chicken with gravy | FD | Vacuum: 27 in. | 40/ /V | < 6 m | 5.7/9 | | | "F" at time "0": 7.1. Limit of acceptability: 6. | (1) |
| | | | 70/ /V | > 6 m | 6.4/9 | | | | |
| | | | 100/ /V | < 6 m | 5.9/9 | | | | |
| Chicken with vegetables | FD | Vacuum: 27 in. | 40/ /V | > 6 m | 6.4/9 | | | "F" at time "0": 6.2. Limit of acceptability: 6. | (1) |
| | | | 70/ /V | > 6 m | 6.4/9 | | | | |
| | | | 100/ /V | > 6 m | 6.0/9 | | | | |
| Chili con carne | FD | Vacuum: 30 in. | 100/1-2/V | >24 w | 6.5/9 | | | "F" at time "0": 7.0. Limit of acceptability: 6. | |
| | | 28 in. | 100/1-2/V | >24 w | 6.1/9 | | | | |
| | | 26 in. | 100/1-2/V | >24 w | 6.2/9 | | | | |
| | | 24 in. | 100/1-2/V | >24 w | 6.1/9 | | | | |
| | | 22 in. | 100/1-2/V | >24 w | 6.0/9 | | | | |
| | | 20 in. | 100/1-2/V | < 2 w | 5.6/9 | | | | |
| | | 0 in. | 100/1-2/A | < 2 w | 5.2/9 | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | AROMA | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| (continued) | | | | | | | | | |
| Fish creole | FD | Vacuum: 27 in. | 40/ /V | > 3 m | 6.2/9 | | | "F" at time "0": 5.4. Limit of acceptability: 6. | (1) |
| | | | 70/ /V | < 3 m | 5.8/9 | | | | |
| | | | 100/ /V | < 3 m | 5.4/9 | | | | |
| Meat balls with gravy | FD | Vacuum: 27 in. | 40/ /V | > 6 m | 6.2/9 | | | "F" at time "0": 7.3. Limit of acceptability: 6 | (1) |
| | | | 70/ /V | > 6 m | 6.4/9 | | | | |
| | | | 100/ /V | > 6 m | 7.1/9 | | | | |
| Meat food product | FD | Compressed bars | -20/6.6/V | ~2.6 y | 6.0/9 | | | Initial quality score: 7.3. Assumed limit of acceptability: 6. | Cecil & Woodroof (1962) |
| | | | 0/6.6/V | ~ 3 y | 6.0/9 | | | | |
| | | | 32/6.6/V | ~ 2 y | 6.0/9 | | | | |
| | | | 47/6.6/V | ~1.8 y | 6.0/9 | | | | |
| | | | 70/6.6/V | ~0.5 y | 6.0/9 | | | | |
| | | | 100/6.6/V | ~0.2 y | 6.0/9 | | | | |
| Noodles with meat sauce | FD | Vacuum: 27 in. | 40/ /V | > 3 m | 6.7/9 | | | "F" at time "0": 6.5. Limit of acceptability: 6. | (1) |
| | | | 70/ /V | < 3 m | 5.4/9 | | | | |
| | | | 100/ /V | < 3 m | 5.4/9 | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

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|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | TBA Value | | |
| Pork sausage patties, cooked | FD | Control | 21/ /N | <35 w | | | 1.22 | Kena: sodium tripolyphosphate & sodium hexameta-phosphate. | Sharma & Seltzer (1977) |
| | | Control | 100/ /N | >35 w | | | 0.58 | | |
| | | + 0.50% Kena, | 21/ /N | >35 w | | | 0.45 | | |
| | | + 0.38% Kena | 100/ /N | >35 w | | | 0.32 | | |
| Pork with potatoes | FD | Vacuum: 30 in. | 100/1-2/V | >12 w | 6.2/9 | | | "F" at time "O": 6.4. Limit of acceptability: 6. | (2) |
| | | 28 in. | 100/1-2/V | >24 w | 6.0/9 | | | | |
| | | 26 in. | 100/1-2/V | >24 w | 6.0/9 | | | | |
| | | 24 in. | 100/1-2/V | < 2 w | 5.8/9 | | | | |
| | | 22 in. | 100/1-2/V | < 2 w | 5.3/9 | | | | |
| | | 20 in. | 100/1-2/V | < 2 w | 4.6/9 | | | | |
| | | 0 in. | 100/1-2/A | < 2 w | 3.5/9 | | | | |
| Scrambled eggs | FD | Vacuum: 27 in. | 40/ /V | > 24 m | | | | | (1) |
| | | | 70/ /V | > 24 m | | | | | |
| | | | 100/ /V | > 6 m | | | | | |
| Spaghetti with meat sauce | FD | Vacuum: 30 in. | 100/1-2/V | > 24 w | 6.3/9 | | | "F" at time "O": 6.3. Limit of acceptability: 6. | (2) |
| | | 28 in. | 100/1-2/V | > 24 w | 6.0/9 | | | | |
| | | 26 in. | 100/1-2/V | > 12 w | 6.2/9 | | | | |
| | | 24 in. | 100/1-2/V | < 2 w | 4.6/9 | | | | |
| | | 22 in. | 100/1-2/V | < 2 w | 5.0/9 | | | | |
| | | 20 in. | 100/1-2/V | < 2 w | 5.1/9 | | | | |
| | | 0 in. | 100/1-2/A | < 2 w | 3.1/9 | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

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|---|---|---|---|---|---|---|---|---|---|
| Spaghetti with meat sauce (continued) | FD | Vacuum: 27 in. | 40/ /V<br>70/ /V<br>100/ /V | > 3 m<br>< 3 m<br>3 m | 6.7/9<br>5.8/9<br>6.0/9 | | | "F" at time "0": 6.8. Limit of acceptability: 6 | (2) |
| Spaghetti in tomato sauce | FD | Vacuum: 27 in. | 40/ /V<br>70/ /V<br>100/ /V | > 3 m<br>< 6 m<br>< 3 m | 7.1/9<br>5.8/9<br>5.6/9 | | | "F" at time "0": 6.9. Limit of acceptability: 6. | (1) |
| Swiss steak | FD | Vacuum: 27 in. | 40/ /V<br>70/ /V<br>100/ /V | > 6 m<br>> 6 m<br>> 6 m | 6.9/9<br>6.8/9<br>7.1/9 | | | "F" at time "0": 6.4. Limit of acceptability: 6. | (1) |
| Turkey with gravy | FD | Vacuum: 27 in. | 40/ /V<br>70/ /V<br>100/ /V | ~ 6 m<br>> 6 m<br>> 6 m | 5.7/9<br>6.3/9<br>6.1/9 | | | "F" at time "0": 6.2 Limit of acceptability: 6 | (1) |
| Veal/barbecue sauce | FD | Vacuum: 27 in. | 40/ /V<br>70/ /V<br>100/ /V | < 3 m<br>< 3 m<br>< 3 m | 5.5/9<br>5.8/9<br>5.5/9 | | | "F" at time "0": 7.1 | (1) |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

|  |  |  |  |  | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | FLAVOR | AROMA | OTHERS | Comments | Ref. |
| **Soups** |  |  |  |  |  |  |  |  |  |
| Beef rice | FD | Vacuum: 27 in. | 40/ /V<br>100/ /V | > 6 m<br>3 m | 6.5/9<br>6.0/9 |  |  | "F" at time "0": 6.3 | (1) |
| Chicken Noodle | FD | Vacuum: 27 in. | 40/ /V<br>100/ /V | > 6 m<br>< 3 m | 7.5/9<br>4.8/9 |  |  | "F" at time "0": 6.0 | (1) |
| Chicken rice | FD | Vacuum: 27 in. | 40/ /V<br>100/ /V | > 6 m<br>> 3 m | 6.1/9<br>6.1/9 |  |  | "F" at time "0": 6.5 | (1) |
| Cream of mushroom | FD | Vacuum: 27 in. | 40/ /V<br>100/ /V | < 3 m<br>< 3 m | 5.5/9<br>5.7/9 |  |  | "F" at time "0": 6.0 | (1) |
| Pea | FD | Vacuum: 27 in. | 40/ /V<br>100/ /V | < 3 m<br>< 3 m | 5.5/9<br>5.7/9 |  |  | "F" at time "0": 6.0 | Nanz & Lachance (1967) |
| Tomato | FD | Vacuum: 27 in. | 40/ /V<br>100/ /V | > 3 m<br>< 3 m | 6.5/9<br>5.7/9 |  |  | "F" at time"0": 6.0 | (1) |

|  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
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| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

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|---|---|---|---|---|---|---|---|---|---|
| Soups (continued) | | | | | | | | % of responses describing product as good: (after 1 month) | |
| Vegetable | FD | FD Vegetables | 32/ /N | ∿ 3 m | | | | 76.9 | Whurmann, et al. (1959) |
| | | | 100/ /N | > 1 m | | | | 75.0 | |
| | | | 100/ /A | < 1 m | | | | 33.3 | |
| | AD | AD Vegetables | 32/ /N | < 1 m | | | | 28.0 | |
| | | | 100/ /N | < 1 m | | | | 17.2 | |
| | | | 100/ /A | < 1 m | | | | 10.3 | |
| | | | | | | | | Time given is time required to obtain a min. of 60% responses describing the product at good. | |
| Vegetables | | | | | | | | | |
| Carrots with cream sauce | FD | Vacuum: 27 in. | 40/ /V | < 3 m | 5.7/9 | | | "F" at time "0": 6.6. Samples were considered unacceptable. | |
| | | | 70/ /V | < 3 m | 5.2/9 | | | | |
| | | | 100/ /V | < 3 m | 4.7/9 | | | | |
| Cream style corn | FD | Vacuum: 27 in. | 40/ /V | > 6 m | 7.0/9 | | | | |
| | | | 70/ /V | > 3 m | 7.0/9 | | | | |
| | | | 100/ /V | > 6 m | 6.3/9 | | | | (1) |
| Green beans with cream sauce | FD | Vacuum: 27 in. | | | | | | Unacceptable | Nanz & Lachance (1967) |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
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| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | FLAVOR | AROMA | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded | | | | |
| Vegetables (continued) | | | | | | | | | |
| Potatoes (diced) with gravy | FD | Vacuum: 27 in. | 40/ /V<br>70/ /V<br>100/ /V | > 6 m<br>> 6 m<br>> 6 m | 6.7/9<br>6.7/9<br>6.7/9 | | | | (1) |
| Potatoes with parsley | FD | Vacuum: 27 in. | 40/ /V<br>100/ /V | < 3 m<br>< 3 m | 5.0/9<br>4.6/9 | | | "F" at time "O": 6.0 | (1) |
| Potatoes (fried) | FD | Vacuum: 27 in. | 40/ /V<br>100/ /V | < 3 m<br>< 3 m | 4.8/9<br>4.6/9 | | | "F" at time "O": 5.7 | (1) |
| Potatoes (mashed) | FD | Vacuum: 27 in. | 40/ /V<br>70/ /V<br>100/ /V | >24 m<br>>24 m<br>> 6 m | | | | | (1) |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
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| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
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| Food Material | Method of Drying | Additional Treatment | Storage Conditions T($^{O}$F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Beef | FD | "Zero oxygen" | 100/2.0/H-N | 6 m (F) | ∿5.4/9 | | | Beef cubes | Bishov, |
| | | 2% oxygen | 100/2.0/O | 1 m (F) | ∿5.5/9 | | | 9 point scale | et al |
| | | | | | | | | for taste | (1971) |
| | FD | Samples stored | 0/1.7/O | > 5 m | OK | OK | Odor OK | | Thompson |
| | | in atmospheres | 68/1.7/O | < 5 m | | | | Strong F & odor | et al |
| | | containing 0, | 90/1.7/O | < 5 m | | | | Strong F & odor | (1962) |
| | | 0.1, 1.0 & 4% | 0/3.9/O | < 5 m | | | | Strong F & odor | |
| | | oxygen & air. | 68/3.9/O | < 5 m | | | | Strong F & odor | |
| | | | 90/3.9/O | < 5 m | | | | Flat F & vitamin odor | |
| | | | 0/5.1/O | < 5 m | | | | Strong F & odor | |
| | | | 68/5.1/O | < 5 m | | | | Strong F & odor | |
| | | | 90/5.1/O | < 5 m | | | | Flat F & vitamin odor | |
| | | | 0/1.5/A/N | > 5 m | | | | | |
| | | | 70-80/1.5/A/N | < 5 m | | | | Presence of $O_2$ | |
| | | | 90/1.5/A/N | < 5 m | | | | in all containers, | |
| | | | 0/3.0/A/N | < 5 m | | | | no conclusions about | |
| | | | 70-80/3.0/A/N | < 5 m | | | | the effect of $O_2$ | |
| | | | 90/3.0/A/N | < 5 m | | | | | |
| | | | 0/13.0/A/N | < 5 m | | | | | |
| | | | 70-80/13.0/A/N | < 5 m | | | | | |
| | | | 90/13.0/A/N | < 5 m | | | | | |

| | | | | | | | | | | | | | |
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| Food Material | Method of Drying | Additional Treatment | Storage Conditions $T(^{o}F)$/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Beef (cont'd) | FD | Air exposure | 86/1-1.5/H-N | < 12 m | 4.75/9 | 8.7 | Texture 5.67/9 | 1.6% fat content | Bengtsson |
| | | before packaging | 86/1-1.5/H-N | < 12 m | 4.25/9 | 6.9 | 4.83/9 | 7% fat content | & Bengt. (1968) |
| | | No exposure | 86/1-1.5/H-N | < 12 m | 5.83/9 | 14.7 | 5.42/9 | 1.6% fat content | |
| | | before packaging | 86/1-1.5/H-N | < 12 m | 5.25/9 | 12.8 | 6.25/9 | 7.0% fat content CO: Hunter redness a-value | |
| | | 20 min. exposure | 86/1-1.5/O | < 12 m | 4.50/9 | 7.7 | 5.25/9 | Head space $O_2 < 0.2\%$ | |
| | | to air before | 86/1-1.5/H-N | < 12 m | 5.71/9 | 12.5 | 5.75/9 | Head space $O_2 < 0.2\%$* | |
| | | packaging | 86/1-1.5/H-N | < 12 m | 5.71/9 | 12.5 | 5.83/9 | Head space $O_2$:4% * | |
| | | No exposure to air before packaging. | 86/1-1.5/H-N | < 12 m | 5.54/9 | 13.7 | 5.83/9 | Head space $O_2 < 0.1\%$ | |
| | | | 86/1-1.5/N | < 7 m | 5.25/9 | 9.9 | 3.33/9 | | |
| | | | 86/1-1.5/H-N | < 7 m | 5.08/9 | 8.5 | 3.00/9 | | |
| | | | 86/1-1.5/CO | < 7 m | 4.82/9 | 8.8 | 2.64/9 | | |
| | | | -22/1-1.5/H-N | < 8 m | 5.67/9 | 13.3 | 7.08/9 | All of these samples | |
| | | | 37/1-1.5/H-N | < 8 m | 5.67/9 | 8.1 | 6.83/9 | with an $O_2$ scavenger | |
| | | | 86/1-1.5/H-N | < 8 m | 4.33/9 | 8.6 | 6.25/9 | | |
| | | 1% fat content | -22/1-1.5/H-N | < 8 m | 5.88/9 | 14.6 | 7.13/9 | Juiciness was | |
| | | " | 37/1-1.5/H-N | > 8 m | 6.12/9 | 8.0 | 7.00/9 | inversely propor- | |
| | | " | 86/1-1.5/H-N | ≤ 8 m | 5.62/9 | 5.3 | 6.13/9 | tional to storage temperature. | |

* Plus oxygen scavenger

| | | | | | | | | | | | |
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| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
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|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Texture | | |
| Beef (cont'd) | FD | 3.9% fat content | -22/1-1.5/H-N | < 8 m | 5.50/9 | 17.8 | 6.63/9 | Assumed limit of acceptability "6" | |
| | | " " " | 37/1-1.5/H-N | < 8 m | 4.88/9 | 8.2 | 6.25/9 | | |
| | | " " " | 86/1-1.5/H-N | < 8 m | 3.88/9 | 4.6 | 5.63/9 | | |
| | FD | Freezing rate: 0.2 cm/H | 86/1-1.5/V | < 8 m | 4.58/9 | 8.0 | 3.92/9 | Oxygen content for these samples <0.3%. | Bengtsson & Bengtsson (1968) |
| | | Freezing rate: 0.6 cm/H | 86/1-1.5/V | < 8 m | 4.75/9 | 8.1 | 3.42/9 | | |
| | | Freezing rate: 20-30 cm/H | 86/1-1.5/V | < 8 m | 5.17/9 | 7.9 | 3.25/9 | Very high freezing rate, lowered re-constitution ability. | |
| | | Surface T during Dehydration | | | | | | | |
| | | 68° F | 86/1-1.5/V | < 8 m | 5.42/9 | 8.0 | 6.67/9 | Surface temp had little effect on quality over the range studied. | |
| | | 104° F | 86/1-1.5/V | < 8 m | 5.08/9 | 9.5 | 6.42/9 | | |
| | | 140° F | 86/1-1.5/V | < 8 m | 5.08/9 | 10.3 | 6.00/9 | | |
| | FD | Oven-broiled. Visible fat not removed. Rehydrated in beef bouillon. | 40/2.0/N | <4 m | 5/9 | 5/9 | 5/9 | F at time 0: 4 | Tappel, et al. (1957) |
| | | | 70/2.0/N | <4 m | 4/9 | 5/9 | 5/9 | CO at time 0: 7 | |
| | | | 100/2.0/N | <4 m | 4/9 | 4/9 | 4/9 | TE at time 0: 4 | |
| | FD | Oven-broiled: visible fat removed. Rehydrated in beef bouillon. | 40/2.0/N | > 6 m | 6/9 | 7/9 | 6/9 | F at time 0: 6 | |
| | | | 130/2.0/N | <6 m | 4/9 | 4/9 | 4/9 | CO at time 0: 7 | |
| | | | | | | | | TE at time 0: 7 | |

| | | | | | | | | | | | |
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Meat & Meat Products (continued)

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Beef (cont'd) | FD | Pressure-cooked, rehydrated in beef bouillon. | 40/2.0/N | < 6 m | 5/9 | 5/9 | 6/9 | F at time 0: 6 | |
| | | | 70/2.0/N | ∿ 6 m | 6/9 | 6/9 | 5/9 | CO at time 0: 7 | |
| | | | 100/2.0/N | ∿ 6 m | 6/9 | 6/9 | 5/9 | TE at time 0: 6 | |
| | | | 130/2.0/N | ∿ 6 m | 6/9 | 5/9 | 6/9 | | |
| Beef (veal) | FD | Oven-braised, rehydrated in beef bouillon. | 40/2.0/N | < 6 m (TE) | 6/9 | 8/9 | 4/9 | F at time 0: 7 | |
| | | | 70/2.0/N | > 6 m | 7/9 | 9/9 | 7/9 | CO at time 0: 8 | |
| | | | 100/2.0/N | > 6 m | 7/9 | 8/9 | 6/9 | TE at time 0: 5 | |
| | | | 130/2.0/N | < 6 m (TE) | 6/9 | 6/9 | 4/9 | | |
| | VD | VD in fat. Surface fat removed. | 32/2.5/A/N | ∿ 14m | | | | Grade score as estimate of shelf life, with lower limit of acceptability: 2. | Prater, et al (1960) |
| | | | 68/2.5/A/N | ∿ 10m | | | | | |
| | | | 99/2.5/A/N | ∿ 7 m | | | | | |
| | | | | | A | B | C | | |
| | FD | + IPD + Oxyban | 100/ /N | ∿ 6 m (F) | 56% | 64% | 2.9% | A, water soluble proteins (% N recovered). B, 0.15µ extract sarcoplasmic (% N recovered). C, C, 0.53µ extract (actomyosin) (% N recovered). Profound biochemical damage after 6m (100°F). | Cole, (1962) |
| | | control | -20/ /N | > 6 m | 100% | 100% | 100% | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Soluble Protein | | |
| | FD | | 130/ 0/A | | | | < 55% | Values obtained after 16 days of storage | Regier and Tappel (1956) |
| | | | 130/ 4.0/A | | | | < 35% | | |
| | | | 130/ 7.7/A | | | | < 20% | | |
| | | | 130/12.3/A | | | | < 10% | | |
| | | | 130/19.4/A | | | | < 5% | | |
| | | | | | | A* | Soluble N Cpds. | | |
| | | | 70/ 3.0/A | | | <85% | <100% | After 54 days | |
| | | | 95/ 3.0/A | | | <50% | < 85% | After 54 days | |
| | | | 130/ 3.0/A | | | <25% | < 55% | After 15 days | |
| | | | 160/ 3.0/A | | | < 5% | < 45% | After 2 days<br>* A: % retention of hematin pigments | |
| | FD | Accelerated FD, | | | A | | B | | |
| | | -IPD | 99/ 3.0/N | >12 m (P) | 2.5-3 | | 3-3.5 | A palatability of 2.5 was considered limit of acceptability<br>(P)A: Palatability scale: 1-9.<br>B: toughness scale: 0-6.<br>6: tender | Hunt & Matheson (1959) |
| | | +IPD | 99/ 2.8/N | >12 m (P) | 4-4.5 | | 2-2.5 | | |
| | | -IPD | 68/ 3.0/N | >12 m (P) | 6-6.5 | | 4-4.5 | | |
| | | -IPD | 99/ 6.3/N | < 5 m (P) | 2-2.5 | | 2-2.5 | | |
| | | -IPD | 99/10.8/N | < 5 m (P) | 1.5-2 | | 2-2.5 | | |
| | | -IPD | 64/ 3.3/N | >12 m (P) | 4.5-5 | | 3.5-4.0 | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

Meat and Meat Products (continued)

| Food Material | Method of Drying | Additional Treatment | Storage Conditions $T(^{o}F)$/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Texture | | |
| Lamb | FD | Rib, loin & | 40/2.0/N | ~ 6 m | 6/9 | 6/9 | 5/9 | F at time 0: 7 | Tappel, et |
| | | sirloin chops. | 70/2.0/N | > 6 m | 6/9 | 7/9 | 6/9 | CO at time 0: 9 | al (1957) |
| | | Oven braised. | 100/2.0/N | > 6 m | 6/9 | 7/9 | 6/9 | TE at time 0: 7 | |
| | | | 130/2.0/N | < 6 m | 6/9 | 5/9 | 4/9 | | |
| | | Cooked mutton | | | Stale F | | Grade Score | | |
| | AD | mince | 77/5.25/A | < 6 m | 4.98/8 | | 0.52/4 | Grade score an | Prater & |
| | | $N_2$+ 4.3% $O_2$ | 77/5.25/N | >30 m | 2.52/8 | | 2.62/4 | estimate of | Elliott |
| | | $N_2$+ 2.5% $O_2$ | 77/5.25/N | >30 m | 2.48/8 | | 2.69/4 | shelf life with | (1959) |
| | | $N_2$+ 1.4% $O_2$ | 77/5.25/N | >30 m | 2.46/8 | | 2.69/4 | a lower limit of | |
| | | | | | | | | acceptability: 2. | |
| | | | 77/5.25/N | >30 m | 2.75/8 | | 2.44/4 | Stale flavor: 8-0 | |
| | | | 77/5.25/CO | >30 m | 2.69/8 | | 2.48/4 | (8 stale). | |
| | | | 77/5.25/A | | 5.97/8 | | 0.18/4 | Large free space | |
| | | $N_2$ + 4/3% $O_2$ | 77/5.25/N | | 2.64/8 | | 2.55/4 | " " " | |
| | | $N_2$ + 2.5% $O_2$ | 77/5.25/N | | 1.91/8 | | 3.20/4 | " " " | |
| | | $N_2$ + 1.2% $O_2$ | 77/5.25/N | | 1.82/8 | | 3.29/4 | " " " | |
| | | | 77/5.25/N | | 1.89/8 | | 3.22/4 | " " " | |
| | | | 77/5.25/CO | | 1.82/8 | | 3.22/4 | " " " | |
| | | | 77/5.25/A | | 4.99/8 | | 0.61/4 | Small free space | |
| | | $N_2$ + 4.3% $O_2$ | 77/5.25/N | | 2.08/8 | | 3.08/4 | " " " | |
| | | $N_2$ + 2.5% $O_2$ | 77/5.25/N | | 1.87/8 | | 3.28/4 | " " " | |
| | | $N_2$ + 1.2% $O_2$ | 77/5.25/N | | 1.85/8 | | 3.30/4 | " " " | |
| | | | 77/5.25/N | | 1.91/8 | | 3.23/4 | " " " | |
| | | | 77/5.25/CO | | 1.87/8 | | 3.29/4 | " " " | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

Meat and Meat Products (continued)

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T($^{o}$F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Pork | FD | "Zero oxygen" | 100/2.0/H-N | 8 m (F) | | | | | Bishov, et al (1971) |
| | | 2% oxygen | 100/2.0/O | 2 m (F) | | | | | |
| | FD | Raw | 82/1.0/N | < 6 m | 18/36 | | | Control at -40$^{o}$ F Triangle test: (F) Based on scoring data, the 82$^{o}$ F samples (raw & cooked) stored for 6 months were not significantly different from control. | Townsend, et al (1978) |
| | | | 100/1.0/N | < 3 m | 23/32 | | | | |
| | | | 118/1.0/N | < 3 m | 28/32 | | | | |
| | | Cooked | 82/1.0/N | < 1 m | 18/32 | | | | |
| | | | 100/1.0/N | < 1 m | 16/32 | | | | |
| | | | 118/1.0/N | < 1 m | 19/32 | | | | |
| | | | | | | | Texture | | |
| | FD | Oven braised visible fat not removed. Rehydrated in bouillon | 40/2.0/N | > 6 m | 7/9 | 7/9 | 6/9 | F at time 0: 6 | Tappel, et al (1957) |
| | | | 70/2.0/N | < 6 m | 5/9 | 7/9 | 6/9 | CO at time 0:7 | |
| | | | 100/2.0/N | > 6 m | 4/9 | 3/9 | 5/9 | TE at time 0:6 | |
| | FD | Oven braised. Visible fat removed. Rehydrated in beef bouillon. | 40/2.0/N | ~ 6 m (TE) | 7/9 | 7/9 | 5/9 | F at time 0: 9 | |
| | | | 130/2.0/N | < 6 m | 6/9 | 5/9 | 4/9 | CO at time 0: 9 TE at time 0: 8 | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Tr^atment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Pork (ham) | FD | | 70/3-5/N | < 20 w | | | | Samples stored at 70° F rated better than corresponding samples at 100° F. | Anglemier (1960) |
| | | | 70/3-5/CO | < 20 w | | | | | |
| | | | 70/3-5/V | 22 w | | | | | |
| | | | 100/3-5/N | < 20 w (F&O) | | | | | |
| | | | 100/3-5/CO | < 20 w (F&O) | | | | | |
| | | | 100/3-5/V | 22 w | | | | | |
| | | | | | | | TBA(535 mμ) | | |
| | | | 0/6.4/ | | 5.6/9 | 5.7/9 | 0.50 | Samples above 7.5% moisture rated lower than samples below 7.5%. | |
| | | | 0/8.1/ | | 4.3/9 | 5.5/9 | 0.42 | | |
| | | | 70/4.4/ | | 5.8/9 | 6.4/9 | 0.33 | | |
| | | | 70/6.3/ | | 6.0/9 | 6.5/9 | 0.29 | | |
| | | | 70/8.7/ | | 5.7/9 | 5.9/9 | 0.27 | | |
| | | | 70/11.4/ | | 5.4/9 | 4.9/9 | 0.31 | | |
| | | | 100/4.2/ | | 5.5/9 | 5.9/9 | 0.30 | | |
| | | | 100/6.2/ | | 5.2/9 | 5.4/9 | 0.28 | | |
| | | | 100/8.6/ | | 5.0/9 | 4.4/9 | 0.28 | | |
| | | | 100/11.1/ | | 5.3/9 | 4.5/9 | 0.24 | | |
| | | | /3-5/N | < 22 w | 4.8/9 | 4.4/9 | | Color changes were observed as early as 6 weeks at 70 & 100° F. Initial F & CO scores scores were approximately 7. | |
| | | | /3-5/CO | < 22 w | 4.7/9 | 4.6/9 | | | |
| | | | /3-5/V | < 22 w (F) | 5.4/9 | 4.8/9 | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

## FISH

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Mackerel | Sun D | | 78/44.1/A | 21 d (fungus) | | brown | | CTC: chlortetra- | Sen, et al |
| | | 50 ppm CTC & salting | 78/39.9/A | 21 d (fungus) | | brown | | cycline | (1961) |
| | | Salting + 50 ppm CTC | 78/38.7/A | 21 d (fungus) | | brown | | In general, Sun D | |
| | | salting + 50 ppm CTC + 19% Na propionate | 78/42.0/A | <70 d (odor) | | brown | | fish was tough and hard | |
| | | 10% Na propionate | 78/42.0/A | <70 d (odor) | | brown | | | |
| | | Salting + Na benzoate + $NaH_2PO_4$ | 78/41.0/A | <70 d (odor) | | brown | | | |
| | | | | | | | Texture | | |
| | Sun D | | 100/92% r.h/A | <62 d | | | Not tough | Intense fish | Sen, et al |
| | | | 78/75% r.h/A | <62 d | | | tough | smell, fibrous | (1961) |
| Oysters | FD | Whole | 40/2.0/N | > 3 m | 6/9 | 7/9 | 9/9 | F at time 0: 7 | Tappel, et al (1957) |
| | | | 70/2.0/N | > 2 m | 8/9 | 9/9 | 9/9 | CO at time 0: 9 | |
| | | | 100/2.0/N | > 2 m | 8/9 | 7/9 | 9/9 | TE at time 0: 9 | |
| | | | 130/2.0/N | > 2 m | 6/9 | 6/9 | 8/9 | | |
| Salmon | FD | Steaks, baked | 40/2.0/N | > 6 m | 9/9 | 8/9 | 8/9 | F at time 0: 9 | |
| | | | 70/2.0/N | > 6 m | 9/9 | 8/9 | 9/9 | CO at time 0: 9 | |
| | | | 100/2.0/N | > 6 m | 9/9 | 7/9 | 8/9 | TE at time 0: 6 | |
| | | | 130/2.0/N | < 3 m (CO) | 7/9 | 4/9 | 7/9 | | |
| Tuna | FD | Steaks, baked | 40/2.0/N | > 6 m | 7/9 | 8/9 | 6/9 | F at time 0: 9 | |
| | | | 70/2.0/N | > 6 m | 8/9 | 6/9 | 8/9 | CO at time 0: 9 | |
| | | | 100/2.0/N | > 6 m | 9/9 | 7/9 | 8/9 | TE at time 0: 9 | |
| | | | 130/2.0/N | > 6 m | 8/9 | 7/9 | 6/9 | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

Fish (continued)

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Texture | | |
| Shrimp | FD | Whole | 40/2.0/N | > 6 m | 8/9 | 8/9 | 8/9 | F at time 0: 8 | |
| | | | 70/2.0/N | > 6 m | 8/9 | 8/9 | 8/9 | CO at time 0: 7 | |
| | | | 100/2.0/N | < 6 m | 6/9 | 7/9 | 8/9 | TE at time 0: 8 | |
| | | | 130/2.0/N | < 6 m (CO) | 6/9 | 4/9 | 7/9 | | |
| | FD | | | | 8/10 | 8/10 | 8/10 | | Moorjani & |
| | FD | Mild blanching | | | 7/10 | 7/10 | 8/10 | | Dani |
| | AD | | | | 6/10 | 8/10 | 4/10 | Unacceptable | (1968) |
| | | | | | | | Primary Amines | | |
| | FD | | 14/1.6/A | > 3 w | 7.4/9 | | 9.6 | | Melpar |
| | | | 100/1.6/A | > 3 w | 7.7/9 | | 33.6 | | (1964) |
| | | | 100/5.4/A | > 3 w | 6.3/9 | | 28.7 | | |
| | | | 100/6.6/A | > 3 w | 6.5/9 | | 67.1 | | |
| | | | 100/10.1/A | > 3 w | 6.5/9 | | 57.5 | | |
| | | | 100/18.0/A | > 3 w | 6.9/9 | | 47.9 | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

# POULTRY

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Chicken (white meat) | FD | "Zero oxygen"<br>" 2% oxygen | 100/2.0/H-N<br>100/2.0/O | 12 m (F)<br>5 m (F) | | | | | Bishov, et al. (1971) |
| Chicken (dark meat) | FD | "Zero oxygen"<br>2% oxygen | 100/2.0/H-N<br>100/2.0/O | 12 m (F)<br>2 m (F) | | | | | Bishov, et al (1971) |
| | FD | Cooked | 82/1.0/N<br>100/1.0/N<br>118/1.0/N | ~ 3 m? (F)<br>< 3 m (F)<br>< 1 m (F) | 17/32<br>17/32<br>17/32 | | | Control -40° F. F: triangle test. | Townsend et al (1978) |
| | FD | Chicken thighs Oven-braised. Rehydrated in bouillon. | 40/2.0/N<br>70/2.0/N<br>100/2.0/N<br>130/2.0/N | > 6 m<br>> 6 m<br>> 6 m<br>< 4 m | 8/9<br>7/9<br>7/9<br>5/9 | 7/9<br>8/9<br>8/9<br>5/9 | Texture<br>8/9<br>7/9<br>6/9<br>5/9 | F at time 0: 9.<br>CO at time 0: 8<br>TE at time 0: 8 | Tappel, et al (1957) |
| Turkey | FD | Thighs & legs sliced. Oven braised. Rehydrated in chicken bouillon | 40/2.0/N<br>70/2.0/N<br>100/2.0/N<br>130/2.0/N | > 6 m<br>< 6 m<br>> 6 m<br>~ 6 m | 7/9<br>5/9<br>6/9<br>6/9 | 8/9<br>6/9<br>6/9<br>7/9 | 8/9<br>6/9<br>7/9<br>5/9 | F at time 0: 7<br>CO at time 0: 7<br>TE at time 0: 8 | Tappel, et al. (1957) |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | K-Cl Soluble N | | |
| Turkey (cont'd). | FD | | 99/0.8/N | > 90 d (F) | OK | 164/40 | 44.8/52.2 | *Fat-free tissue CO given as absorption of aqueous extracts at 350 nm x 100 after 76 days. Denominator gives value at time 0. K-Cl soluble N after 76 days. Rapid deterioration of haem pigments in all samples after 10 days. | Fishwick and Zmarlicki (1970) |
| | | | 99/5.0/N | < 90 d (F) | bitter | 263/40 | 43.8/52.2 | | |
| | | | 99/7.3/N | < 90 d (F) | bitter | 481/40 | 41.8/52.2 | | |
| | | | 99/0.8/A | << 90 d (F) | off-flavor | 182/40 | 42.9/52.2 | | |
| | | | 99/0.9*/A | > 90 d (F) | OK | 180/40 | 9.7/16.6 | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

## MILK

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Peroxide Value | | |
| Milk | SD | Whole milk,control | 68/2-3/A | ~ 200 d | 2.0/5.0 | | 1.4 | Peroxide value: m-equiv./kg. fat. Flavor score: 0-5. 0= as good as fresh milk, 5= very strong tallowy flavor. 2= unacceptable. All antioxidants present at a conc. of 0.01% in the powder. | Abbot & Waite (1962) |
| | | Whole milk,control | 99/2-3/A | < 200 d | 3.5/5.0 | | 3.0 | | |
| | | 3,7,8,2',5'- penta- | 68/2-3/A | < 200 d | 2.3/5.0 | | 1.1 | | |
| | | hydroxyflavone. | 99/2-3/A | < 200 d | 3.5/5.0 | | 5.0 | | |
| | | 6-ethyl-3',7,2',5'- | 68/2-3/A | > 200 d | 1.0/5.0 | | 0.7 | | |
| | | trihydroxyflavone | 99/2-3/A | < 200 d | 2.8/5.0 | | 1.1 | | |
| | | 7,8-dimethoxy-3,2' | 68/2-3/A | > 200 d | 0.8/5.0 | | 0.7 | | |
| | | 5'-trihydroxyflavone | 99/2-3/A | < 200 d | 2.8/5.0 | | 0.8 | | |
| | | 6-dodecyl-3,7,2',5- | 68/2-3/A | > 200 d | 1.2/5.0 | | 0.5 | | |
| | | tetrahydroxyflavone | 99/2-3/A | ~ 200 d | 2.0/5.0 | | 0.4 | | |
| | | Butylhydroxyflavone | 68/2-3/A | < 200 d | 2.2/5.0 | | 0.9 | | |
| | | " | 99/2-3/A | < 200 d | 2.6/5.0 | | 0.8 | | |
| | | Nordihydroguaiar-etic acid | 68/2-3/A | > 320 d | 1.8/5.0 | | 0.5 | | |
| | | | 99/2-3/A | > 200 d | 1.8/5.0 | | 0.4 | | |
| | | Propyl gallate | 68/2-3/A | ~ 320 d | 2.0/5.0 | | 0.6 | | |
| | | " " | 99/2-3/A | > 200 d | 1.7/5.0 | | 0.3 | | |
| | | Dodecyl gallate | 68/2-3/A | > 320 d | 1.6/5.0 | | 0.3 | | |
| | | " " | 99/2-3/A | > 200 d | 1.8/5.0 | | 0.3 | | |
| | SD | Whole milk | 63/2.4/N | >81-112 w | 0.7/3.0 | | | Flavor scale: 0-3. 0 = No off-flavor 3 = Definite tallowy flavor 2 = Limit of acceptability | Abbot, et al. (1961) |
| | | | 63/2.2/N-H | >81-112 w | 0.6/3.0 | | | | |
| | | | 99/2.2/N | >81-112 w | 1.2/3.0 | | | | |
| | | | 99/2.2/N-H | >81-112 w | 1.1/3.0 | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

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|---|---|---|---|---|---|---|---|---|---|
| Milk cont'd | SD | Skimmed milk | 63/2.4/N | > 81-112 w | 0.9/3.0 | | | Flavor scale: 0-3 | |
| | | | 63/2.4/N-H | > 81-112 w | 1.1/3.0 | | | 0 = No off-flavor | |
| | | | 99/2.4/N | > 81-112 w | 1.9/3.0 | | | 3 = Definite card-board flavor | |
| | | | 99/2.4/N-H | > 81-112 w | 1.6/3.0 | | Oxidized Flavor | 2 = Limit of acceptability | |
| | VFD | Whole milk | 80/2-3/A | < 6 m | ~29.3 | | 75% | Flavor score:0-40 The lower score, the lower the quality. Oxidized flavor: % occurrence. Initial flavor score: 35.6 | Tamsma, et al. (1961) |
| | | 1% oxygen | 80/2-3/N | < 6 m | ~33.0 | | 64% | | |
| | | 0.1% oxygen | 80/2-3/N | < 6 m | ~34.6 | | 46% | | |
| | | Whole milk | 39/ /H-N | | 35.4 | | | Taste score from 31-40. Initial flavor score 37.1. Flavor scores after 6 months. | Tamsma, et al. (1974) |
| | | Whole milk | 81/ /H-N | | 34.5 | | | | |
| | | Skim milk + deodorized fat | 39/ /H-N | | 35.9 | | | | |
| | | | 81/ /H-N | | 35.9 | | | | |
| | SD | Whole milk | | | | | | | |
| | | Bulk density: .25 | 39/2.4/H-N | >6 m | 35.1 | | | Taste score from 31-40. Flavor scores after 6 months. Initial flavor scores 36.5, 36.6 & 36.7 respectively. Most flavor losses occurred in the first 2 months. | Tamsma & Sutton (1975) |
| | | Bulk density: .4 | 39/2.9/H-N | >6 m | 35.0 | | | | |
| | | Bulk density: .6 | 39/2.7/H-N | >6 m | 35.2 | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
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Milk (continued)

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | A | | |
| | VFD | Whole milk, continuous | 40/2.8-4.1/N | > 9 m | ~36.5 | | | Initial flavor score: ~ 39.3 | Aceto, et al |
| | | vacuum foam-dried | 73/2.8-4.1/N | <10 w | ~34.8 | | > 15% | Initial flavor score: ~ 38.4 | (1966) |
| | | Batch vacuum foam-dried | 73/2.8-4.1/N | <10 w | | | < 50% | A: % of judgings with "oxidized" comments. | |
| | VFD | Whole milk | 73/1.10/N | | 2 w | | | Oxygen level in | Aceto, |
| | | | 73/1.13/N | | 4 w | | | containers was 0.3- | et al. |
| | | | 73/1.27/N | | 2 w | | | 1.1%. Flavor scores | (1965) |
| | | | 73/2.41/N | | 2 w | | | given as time to reach | |
| | | | 73/2.59/N | | 4 w | | | a significant level | |
| | | | 73/2.84/N | | 13 w | | | of difference between | |
| | | | 73/3.23/N | | 10 w | | | fresh control + stored | |
| | | | 73/4.39/N | | 13 w | | | sample=5% or less. | |
| | | | 73/5.11/N | | 10 w | | | | |
| | VFD | Whole milk | | | | | | Freshly dried milk | |
| | | -IPD | 73/1.10/N | | 3.40 | | | score: 2.14 | |
| | | +IPD | 73/1.10/N | | 3.47 | | | 2.14 | |
| | | -IPD | 73/1.13/N | | 3.35 | | | 2.15 | |
| | | +IPD | 73/1.13/N | | 3.50 | | | 2.15 | |
| | | -IPD | 73/1.27/N | | 3.42 | | | 2.13 | |
| | | +IPD | 73/1.27/N | | 3.45 | | | 2.13 | |
| | | -IPD | 73/2.41/N | | 3.25 | | | 2.17 | |
| | | +IPD | 73/2.41/N | | 3.59 | | | 2.17 | |
| | | -IPD | 73/2.84/N | | 3.14 | | | 2.31 | |
| | | +IPD | 73/2.84/N | | 3.55 | | | 2.31 | |
| | | -IPD | 73/3.23/N | | 3.25 | | | 2.26 | |
| | | +IPD | 73/3.23/N | | 3.49 | | | 2.26 | |
| | | | | | | | Flavor scores: 2-4 | Storage period: 26 W | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
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| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
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Milk (continued)

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | VPD | Iron fortified | 38/ /N | | 38.33/38.59 | | | Flavor scores at time: 10 m/time: 0 | Schoppet, et al (1974) |
| | | Without iron | 38/ /N | | 37.83/37.83 | | | | |
| | SD | Whole milk, cooled in $N_2$ | 41/4.0/N | | ∿36.3 | | | Initial flavor score: ∿36.9 | Hanrahan, et al (1967) |
| | | Whole milk cooled in $CO_2$ | 41/4.0/N | | ∿36.1 | | | ∿36.3 | |
| | | Whole milk, cooled in air | 41/4.0/N | | ∿35.6 | | | ∿36.2 Flavor scores after 4 months of storage | |
| | | Whole milk, Kaempferol added | 68/ | 3-4 m | | | | | Radaeva, et al (1974) |
| | | Quercetin added | 68/ | 12 m | | | | | |
| | | No antioxidant | 68/ | < 8 m | | | | | |
| | | Whole milk, packed in clear glass | 64-68/ /A | <18 m | | | | Cabbage-like off-flavor | Kavalenko & Norkina (1973) |
| | | Packed in brown glass | 64-68/ /A | <18 m | | | | Slightly oxidized off-flavor | |
| | | Packed in cans | 64-68/ /N | ∿18 m | | | | Hardly perceptible oxidized off-flavor | |
| | | Packed in cans | 64-68/ /A | <18 m | | | | Slightly oxidized off-flavor | |
| | | Whole milk, no light | 68-78/ /A | ∿ 8 m | | | | | Kopecky (1978) |
| | | Exposed to light | 68-73/ /A | 1 w | Tallowy | | | | |

| | | | | | | | | | | | |
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|---|---|---|---|---|---|---|---|---|---|
| | | Nonfat milk solids Vacuum: 6.5 in. | 100/2.9/V | 18-24 m (F+D) | | Darkening | | | Cecil & Woodroof (1962) |
| | | | 70/2.9/V | 3-4 y (F+O) | | ~OK | | | |
| | | | 47/2.9/V | ~ 4 y (F+O) | | OK | | | |
| | | | 32/2.9/V | 6-7 y (F+O) | | OK | | | |
| | | | 0/2.9/V | 6-7 y (F+O) | | OK | | | |
| | | | -20/2.9/V | 6-7 y (F+O) | | OK | | | |
| | | Whole milk Vacuum: 8.1 in | 100/2.3/V | 18-24 m (F) | | Darkening | | Samples stored at 70°F were considered better than samples stored at 47 or 32°F. | |
| | | | 70/2.3/V | 3 y (F) | | OK | | | |
| | | | 47/2.3/V | 4 y (F) | | OK | | | |
| | | | 32/2.3/V | 7 y (F) | | OK | | | |
| | | | 0/2.3/V | 7 y (F) | | OK | | | |
| | | | -20/2.3/V | 7 y (F) | | OK | | | |
| | | Conventional or instant dried | 72/ /A | ~45 w (F) | | | | | Baldwin & Humphries (1976) |
| | FSD | Conventional Drying | | | | | | | |
| | | | 0/ /H-N | ~ 6 m (F) | ~35.1 | | | Control | Kurtz, et al (1971) |
| | | | 39/ /H-N | ~ 4 m (F) | ~35.1 | | | " | |
| | | | 80/ /H-N | <0.5 m (F) | ~34.8 | | | " | |
| | | | 0/ /H-N | > 6 m (F) | ~35.7 | | | Deodorized fat | |
| | | | 39/ /H-N | > 6 m (F) | ~35.5 | | | " " | |
| | | | 80/ /H-N | < 4 m (F) | ~34.8 | | | " " | |
| | | Dried with ozone-free air | 39/ /H-N | >6 m (F) | ~35.3 | | | Control | |
| | | | 80/ /H-N | ~3 m (F) | ~34.9 | | | " | |
| | | | 39/ /H-N | > 6 m (F) | ~36.5 | | | Deodorized fat | |
| | | | 80/ /H-N | > 6 m (F) | ~35.8 | | | " " | |
| | | | | | | | | Fresh milk: 37.0 | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
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| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
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| | | | | | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded | | | | |
| | VFD | Whole milk | | | MFS | | | MFS: mean flavor scores averaged over 2, 4 and 6 months. | Tamsma, et al (1962) |
| | | 145°F 30 min + 165°F 30 min on conc. | 80/2.5/0.1% $O_2$ | | 35.28* | | | | |
| | | 145°F 30 min. | 80 2.5/0.1% $O_2$ | | 35.32* | | | | |
| | | 165°F 30 min. | 80/2.5/1.0% $O_2$ | | 35.24* | | | * Statistically indistinguishable. | |
| | | 165°F 30 min. | 80/2.5/0.1% $O_2$ | | 35.23* | | | | |
| | | 185°F 30 min. | 80/2.5/1.0% $O_2$ | | 35.17* | | | MFS ranking is highly deceptive without consideration of types of flavors. | |
| | | 185°F 30 min. | 80/2.5/0.1% $O_2$ | | 35.09* | | | | |
| | | 145°F 30 min. + 165°F 30 min. on conc. | 80/2.5/1.0% $O_2$ | | 34.56* | | | | |
| | | 165°F 30 min. | 80/2.5/A | ~6 m | 34.28 | | | As oxidative determination is checked by heat treatments in excess of pasteurization increased cooked flavor is noted. | |
| | | 145°F 30 min. | 80/2.5/1% $O_2$ | | 33.15 | | | | |
| | | 185°F 30 min. | 80/2.5/A | | 33.09 | | | | |
| | | 145°F 30 min. + 165°F 30 min. on conc. | 80/2.5/A | | 32.20 | | | | |
| | | 145°F 30 min. | ~80/2.5/A | | 31.69 | | | | |
| | | 150°F 6 min. | 80/2.5/0.1% $O_2$ | | 36.23 | | | | |
| | | 145°F 30 min. | 80/2.5/0.1% $O_2$ | | 36.00 | | | | |
| | | 190°F 6 min. | 80/2.5/0.1% $O_2$ | | 35.60 | | | | |
| | | 190°F 6 min. | 80/2.5/1.0% $O_2$ | | 35.46 | | | | |
| | | 170°F 6 min. | 80/2.5/1.0% $O_2$ | | 35.45 | | | | |
| | | 170°F 6 min. | 80/2.5/0.1% $O_2$ | | 35.33 | | | | |
| | | 190°F 6 min. | 80/2.5/A | | 35.01 | | | | |
| | | 170°F 6 min. | 80/2.5/A | ~6 m | 34.97 | | | | |
| | | 150°F 6 min. | 80/2.5/1.0% $O_2$ | | 34.45 | | | | |
| | | 145°F 30 min. | 80/2.5/1.0% $O_2$ | | 33.71 | | | | |
| | | 145°F 30 min. | 80/2.5/A | | 30.00 | | | | |
| | | 150°F 6 min. | 80/2.5/A | | 30.00 | | | | |

| | | | | | | | | | | | |
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| | | | | | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded | | | | |
| | | 275°F 15 sec. | 80/2.5/1.0% $O_2$ | | 36.01 | | | | |
| | | 165°F 30 min. | 80/2.5/0.1% $O_2$ | | 35.79 | | | | |
| | | 275°F 15 sec. | 80/2.5/0.1% $O_2$ | | 35.48 | | | | |
| | | 165°F 30 min. | 80/2.5/1.0% $O_2$ | | 35.45 | | | | |
| | | 250°F 15 sec. | 80/2.5/1.0% $O_2$ | | 35.44 | | | | |
| | | 225°F 15 sec. | 80/2.5/0.1% $O_2$ | | 35.43 | | | | |
| | | 225°F 15 sec. | 80/2.5/1.0% $O_2$ | | 35.40 | | | | |
| | | 165°F 30 min. | 80/2.5/A | | 35.35 | | | | |
| | | 250°F 15 sec. | 80/2.5/0.1% $O_2$ | | 32.25 | | | | |
| | | 250°F 15 sec. | 80/2.5/A | | 34.62 | | | | |
| | | 225°F 15 sec. | 80/2.5/A | ~6 m | 34.54 | | | | |
| | | 275°F 15 sec. | 80/2.5/A | | 33.92 | | | | |
| | VPD | Whole milk pasteurized 145°F, 30 min. | | | | | | | |
| | | LG | 80/2.5/0.1% $O_2$ | | 36.81 | | | MFS: mean flavor scores averaged over 2,4,6 months. C: no antioxidant | |
| | | C | 80/2.5/0.1% $O_2$ | | 36.69 | | | LG: lauryl gallate | |
| | | PG | 80/2.5/0.1% $O_2$ | | 36.57 | | | PG: propyl gallate | |
| | | LG | 80/2.5/1.0% $O_2$ | | 36.36 | | | DQ: dehydroquercetin | Tamsma et al. (1963) |
| | | PG | 80/2.5/1.0% $O_2$ | | 36.17 | | | Q: quercetin | |
| | | C | 80/2.5/1.0% $O_2$ | | 35.86 | | | NDGA: nordihydro-guiaretic acid, BHA: butylated hydroxy anisole | |
| | | LG | 80/2.5/A | | 34.91 | | | | |
| | | PG | 80/2.5/A | | 33.77 | | | | |
| | | C | 80/2.5/A | | 31.48 | | | | |

| | | | | | | | | | | | |
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Milk (continued)

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|---|---|---|---|---|---|---|---|---|---|
| | | DQ | 80/2.5/1.0% $O_2$ | | 35.48 | | | DLTDP: dilaurylthio-dipropionate<br>SDDC: sodium diethyl-dithiocarbamate<br>AP: Ascorbyl palmitate<br><br>AA: Ascorbic acid<br>antioxidant concentrations: 0.01% in the dry product except AA: 0.3% AP: 0.5% | |
| | | DQ | 80/2.5/0.1% $O_2$ | | 35.45 | | | | |
| | | C | 80/2.5/0.1% $O_2$ | | 35.20 | | | | |
| | | Q | 80/2.5/0.1% $O_2$ | | 35.05 | | | | |
| | | Q | 80/2.5/1.0% $O_2$ | | 34.74 | | | | |
| | | C | 80/2.5/1.0% $O_2$ | | 34.59 | | | | |
| | | Q | 80/2.5/A | | 32.30 | | | | |
| | | C | 80/2.5/A | | 32.07 | | | | |
| | | DQ | 80/2.5/A | | 31.96 | | | | |
| | | C | 80/2.5/0.1% $O_2$ | | 35.42 | | | | |
| | | NDGA | 80/2.5/0.1% $O_2$ | | 35.11 | | | | |
| | | NDGA | 80/2.5/1.0% $O_2$ | | 35.10 | | | | |
| | | C | 80/2.5/1.0% $O_2$ | | 35.02 | | | Effectiveness of antioxidant: LG >PG >NDGA >AP >BHA >AA >DQ >SDDC >TDPA >Q >DLTDP | |
| | | BHA | 80/2.5/0.1% $O_2$ | | 34.75 | | | | |
| | | NDGA | 80/2.5/A | | 33.76 | | | | |
| | | BHA | 80/2.5/0.1% $O_2$ | | 33.07 | | | | |
| | | C | 80/2.5/A | | 32.71 | | | | |
| | | BHA | 80/2.5/A | | 31.88 | | | | |
| | | C | 80/2.5/0.1% $O_2$ | | 34.90 | | | Changes were detected after 6 months in all of the samples | |
| | | DLTDP | 80/2.5/0.1% $O_2$ | | 34.83 | | | | |
| | | C | 80/2.5/1.0% $O_2$ | | 34.78 | | | | |
| | | TDPA | 80/2.5/1.0% $O_2$ | | 34.31 | | | | |
| | | TDPA | 80/2.5/0.1% $O_2$ | | 34.16 | | | None of the antioxidants proved superior to optimum heat treatment of milk prior to drying. | |
| | | DLTDP | 80/2.5/1.0% $O_2$ | | 33.21 | | | | |
| | | C | 80/2.5/A | | 31.87 | | | | |
| | | TDPA | 80/2.5/A | | 31.66 | | | | |
| | | DLTDP | 80/2.5/A | | 31.55 | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | SDDC | 80/2.5/0.1% $O_2$ | | 35.54 | | | | |
| | | SDDC | 80/2.5/1.0% $O_2$ | | 35.47 | | | | |
| | | AA | 80/2.5/0.1% $O_2$ | | 35.14 | | | | |
| | | AP | 80/2.5/0.1% $O_2$ | | 34.93 | | | | |
| | | AP | 80/2.5/1.0% $O_2$ | | 34.76 | | | | |
| | | AA | 80/2.5/1.0% $O_2$ | | 34.50 | | | | |
| | | C | 80/2.5/0.1% $O_2$ | | 33.85 | | | | |
| | | AP | 80/2.5/A | | 33.73 | | | | |
| | | C | 80/2.5/1.0% $O_2$ | | 33.55 | | | | |
| | | AA | 80/2.5/A | | 32.21 | | | | |
| | | C | 80/2.5/A | | 31.14 | | | | |
| | | SDDC | 80/2.5/A | | 30.01 | | | | |
| | | Whole milk pasteurized 165°F, 30 min. | | | | | | | |
| | | BHA | 80/2.5/0.1% $O_2$ | | 36.60 | | | | |
| | | BHA | 80/2.5/1.0% $O_2$ | | 36.36 | | | | |
| | | C | 80/2.5/0.1% $O_2$ | | 36.33 | | | | |
| | | NDGA | 80/2.5/A | | 36.26 | | | | |
| | | C | 80/2.5/1.0% $O_2$ | | 36.06 | | | | |
| | | C | 80/2.5/A | | 36.04 | | | | |
| | | NDGA | 80/2.5/0.1% $O_2$ | | 36.02 | | | | |
| | | NDGA | 80/2.5/1.0% $O_2$ | | 36.85 | | | | |
| | | BHA | 80/2.5/A | | 35.80 | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

Milk (continued)

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | SD | | 194/0 r.h/A | | | 3.83* | | CO given as | Karel & |
| | | | 194/11 r.h/A | | | 6.68* | | browning units | Flink |
| | | | 194/32 r.h/A | | | 71.84* | | at 450 nm. After | (1974) |
| | | | 176/0 r.h/A | | | 2.05 | | 6 hours. | |
| | | | 176/11 r.h/A | | | 2.17 | | * Unacceptable | |
| | | | 176/32 r.h/A | | | 14.27* | | color | |
| | | | 158/0 r.h/A | | | 1.94 | | | |
| | | | 158/11 r.h/A | | | 2.68 | | | |
| | | | 158/32 r.h/A | | | 2.97 | | | |
| | FD | | 194/0 r.h/A | | | 3.68 | | | |
| | | | 194/11 r.h/A | | | 8.12* | | | |
| | | | 194/32/r.h/A | | | 110.8* | | | |
| | | | 176/0 r.h/A | | | 3.49 | | | |
| | | | 176/11 r.h/A | | | 3.53 | | | |
| | | | 176/32 r.h/A | | | 22.29* | | | |
| | | | 158/0 r.h/A | | | 2.21 | | | |
| | | | 158/11 r.h/A | | | 2.24 | | | |
| | | | 158/32 r.h/A | | | 2.98 | | | |
| | SD | Whole milk | 140/3.81/N | 10 d (F+CO) | | | | Log 100y=1.0155 + 0.3956X | Coulter et al (1948) |
| | | | 140/4.49/N | 10 d (F+CO) | | | | | |
| | | | 99/>2.50/N | 8 w (F) | | | | log 100 y=1.0146 + 0.1568X | |
| | | | 68/>2.50/N | 16 w (F) | | | | log 100y=0.7904 + 0.0769X | |
| | | | | | | | | X = % moisture | |
| | | | | | | | | y = Decrease in flavor score/week | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Soluble N | | |
| | | Whole milk | 140/1.90/N | | | | 495/504 | Soluble N: mg/100 ml | |
| | | | 140/2.87/N | | | | 468/502 | (MFB) after 50 days | |
| | | | 140/3.81/N | | | | 29.5/505 | Soluble N at 50d/0d | |
| | | | 140/4.49/N | | | | 30.4/508 | | |
| | Foam D | Air foam, regular | | | A | B | C | | |
| | | | | | 7 | 83 | .1 | Normal fat: 26% | Tamsma et al (1975) |
| | | " | | | 12 | 99 | 0 | Normal fat: 13% | |
| | | " | | | 30 | 94 | .1 | Liquid fat: 26% | |
| | | " | | | 34 | 97 | 0 | Liquid fat: 13% | |
| | | Air foam, low | | | 7 | 81 | .7 | Normal fat: 26% | |
| | | " " " | | | 20 | 92 | .4 | Normal fat: 13% | |
| | | " " " | | | 27 | 86 | .8 | Liquid fat: 26% | |
| | | " " " | | | 40 | 94 | .3 | Liquid fat: 13% | |
| | | $CO_2$ foam, low | | | 14 | 81 | 2.0 | Normal fat: 26% | |
| | | " " " | | | 61 | 95 | .3 | Normal fat: 13% | |
| | | " " " | | | 54 | 86 | 2.0 | Liquid fat: 26% | |
| | | " " " | | | 85 | 98 | .5 | Liquid fat: 13% | |
| | SD | | | | 22 | 73 | 2.7 | Normal fat: 26% | |
| | | | | | 77 | 90 | 1.9 | Normal fat: 13% | |
| | | | | | 99 | 74 | 3.3 | Liquid fat: 26% | |
| | | | | | 99 | 88 | 1.8 | Liquid fat: 13% | |
| | | | | | | | | A: sinkability %<br>B: dispersibility%<br>C: solubility index (ml) | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
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| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded | | | | |
| | | | | | | | Available Lysine | % retention of | Switka, |
| | | Skim milk | 39/75 r.h. | | | | 88% | lysine after | et al |
| | | | 68/75 r.h. | | | | 77% | 24 weeks | (1978) |
| | | | 99/75 r.h. | | | | 51% | | |
| | | | 99/95 r.h. | | | | 27% | | |
| | | Skim milk | 39-41/30-55 r.h. | | | | 100% | % available after: 7 months | Huss, (1974) |
| | | | 68/30-55 r.h. | | | | 78% | : 7 months | |
| | | | 86/30-55 r.h. | | | | 66-69% | : 2 months | |
| | | | | | | B | A | | |
| | | Skim milk | 140/5.70/A | | | 691±115 | 2820±624 | A: half-life of | Dworschak |
| | | | 176/5.70/A | | | 450± 62 | 289± 83 | lysine decomposition | and |
| | | | 212/5.70/A | | | 57± 98 | 29±7.8 | B: half-life of | Hegedus |
| | | | 176/2.45/A | | | 1110±230 | 2010±478 | triptophan decompo- | (1974) |
| | | | 212/2.45/A | | | 118± 17 | 182± 36 | sition | |
| | | | 248/2.45/A | | | 18±3.2 | 14±2.3 | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
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| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

## EGGS

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| Eggs | SD | Acidified | 100/4/CO+N | < 3 m | 4.8/9 | | | Ratings given for | Girardot |
| | | | 70/4/CO+N | >24 m | 6.2/9 | | | scrambled eggs | (1954) |
| | | | 40/4/CO+N | >24 m | 6.2/9 | | | made of these 6 | |
| | | Glucose-free | 100/4/CO+N | >12 m | 6.3/9 | | | types of dehy- | |
| | | | 70/4/CO+N | >18 m | 6.6/9 | | | drated eggs | |
| | | | 40/4/CO+N | >24 m | 6.0/9 | | | Assumed limit of | |
| | | Acidified | 100/2/CO+N | < 6 m | 5.6/9 | | | acceptability: 6 | |
| | | | 70/2/CO+N | >24 m | 6.5/9 | | | | |
| | | | 40/2/CO+N | >24 m | 6.2/9 | | | | |
| | | Glucose-free | 100/2/CO+N | >12 m | 6.4/9 | | | | |
| | | | 70/2/CO+N | >24 m | 6.7/9 | | | | |
| | | | 40/2/CO+N | >24 m | 6.6/9 | | | | |
| | | Acidified | 100/2/N | < 3 m | 5.7/9 | | | | |
| | | | 70/2/N | >24 m | 6.4/9 | | | | |
| | | | 40/2/N | >24 m | 6.4/9 | | | | |
| | | Glucose-free | 100/2/N | >12 m | 6.6/9 | | | | |
| | | | 70/2/N | >24 m | 7.0/9 | | | | |
| | | | 40/2/N | >24 m | 6.2/9 | | | | |
| | | | | | | A | B | | |
| | SD | Untreated | 100/5/N | < 5 w | 2.8/10 | 22.0/32.5 | 60% | A: browning of | Kline |
| | | Acidified | 100/5/N | > 5 w | 6.3/10 | 29.5/33.5 | 73% | powder. % re- | (1954) |
| | | Glucose-free | 100/5/N | > 5 w | 7.4/10 | 32.0/32.5 | 85% | flectance at | |
| | | Acidified | 100/2/CO+N | < 3 m | 5.3/10 | | 94% | 400nµ. Time t/ | |
| | | Glucose-free | 100/2/CO+N | > 6 m | 7.7/10 | 41.5/42.5 | 91% | time 0. | |
| | | Acidified | 100/2/N | < 1 m | 5.4/10 | | 93% | B: protein sol- | |
| | | Glucose-free | 100/2/N | > 6 m | 9.1/10 | 41.5/42.5 | 93% | ubility. Assumed | |
| | | Acidified | 70/2/CO+N | > 6 m | 8.6/10 | | 92% | limit of accept- | |
| | | Glucose-free | 70/2/CO+N | > 6 m | 9.9/10 | | 95% | ability: 6. | |
| | | Acidified | 70/2/N | > 6 m | 7.5/10 | | 93% | | |
| | | Glucose-free | 70/2/N | > 6 m | 9.9/10 | | 95% | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T($^{o}$F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Solubility | Beating Power | | |
| | SD | Dried whole egg | 68/2.3/A | | 21 | --- | 20 | Flavor, solubility & beating power given as % deterioration after 40 weeks. | Hawthorne (1943) |
| | | | 68/2.5/A | | 21 | 6 | 27 | | |
| | | | 68/3.3/A | | 23 | 12 | 13 | | |
| | | | 68/3.5/A | | 33 | 9 | 40 | | |
| | | | 68/3.6/A | | 28 | 11 | 51 | | |
| | | | 68/4.3/A | | 38 | 17 | 47 | | |
| | | | 68/5.0/A | | 36 | 27 | 62 | | |
| | | | 68/5.5/A | | 40 | 24 | --- | | |
| | | | 68/5.9/A | | 50 | 22 | 66 | | |
| | | | 68/6.3/A | | 40 | 24 | 75 | | |
| | | | 68/6.4/A | | 49 | 26 | 65 | | |
| | | | 68/6.6/A | | 37 | 26 | 66 | | |
| | | | 68/6.7/A | | 50 | 31 | 79 | | |
| | | | 68/6.8/A | | 29 | 29 | 68 | | |
| | FD | Dried whole egg | 98/1.2/A | < 8 w | 5.8/10 | | | Limit of acceptability: 6 | Boggs & Fevold (1946) |
| | | | 98/1.2/N | <16 w | 5.6/10 | | | | |
| | | | 98/1.3/A | < 4 w | 5.7/10 | | | | |
| | | | 98/1.3/N | < 4 w | 5.8/10 | | | | |
| | | | 98/1.3/CO | >16 w | 6.4/10 | | | | |
| | | | 98/1.6/A | < 4 w | 5.4/10 | | | | |
| | | | 98/1.6/N | > 4 w | 6.1/10 | | | | |
| | | | 98/0.4/A | < 4 w | 5.6/10 | | | | |
| | | | 98/0.4/N | < 4 w | 5.9/10 | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
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| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
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| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

Eggs (continued)

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | FD | Egg yolk | 98/1.1/A | < 8 w | 5.8/10 | | | | |
| | | | 98/1.1/N | <16 w | 5.7/10 | | | | |
| | FD | Whole egg | | | | | | | |
| | | pH 8.8 | 98/1.8/A | ∼ 2 w | 6.0/10 | | | | |
| | | pH 5.5 | 98/1.9/A | < 8 w | 5.4/10 | | | | |
| | | pH 5.5 | 98/1.7/A | < 8 w | 5.2/10 | | | | |
| | | pH 8.5 | 98/1.2/A | < 4 w | 5.7/10 | | | | |
| | | pH 6.5 | 98/1.1/A | < 8 w | 4.7/10 | | | | |
| | | pH 6.0 | 98/1.2/A | < 8 w | 5.1/10 | | | | |
| | | pH 4.5 | 98/1.0/A | < 2 w | 4.6/10 | | | | |
| | FD | Egg yolk, pH 5.6 | 98/1.3/A | < 8 w | 5.1/10 | | | | |
| | | 6.0 | 98/1.6/A | < 8 w | 5.8/10 | | | | |
| | | 8.5 | 98/1.4/A | < 4 w | 5.2/10 | | | | |
| | AD | Whole egg pH 8.5 | 98/1.2/A | 3-4 w | 6/10 | | | | |
| | | pH 8.5 | 98/1.2/N | 6-8 w | 6/10 | | | | |
| | | pH 8.5 | 98/1.2/CO | >16 w | 6.3/10 | | | | |
| | | pH 5.5 | 98/1.2/A | 8-10 w | 6/10 | | | | |
| | | pH 5.5 | 98/1.2/N | >16 w | 6.7/10 | | | | |
| | | pH 5.5 | 98/1.2/CO | >16 w | 7.2/10 | | | | |
| | FD | Whole egg | 98/0.66/A | > 8 w | | | | Time to obtain scores of 6, minimum level of acceptability (F) | |
| | | | 98/1.2/A | < 6 w | | | | | |
| | | | 98/2.9/A | < 4 w | | | | | |
| | | | 98/3.7/A | < 3 w | | | | | |
| | | | 98/4.3/A | < 3 w | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
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| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
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Eggs (continued)

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | FD | | 4/2/A | > 8 m | ~ 9/10 | | | | |
| | | | 39/2/A | > 8 m | ~8.4/10 | | | | |
| | | | 68/2/A | 8 m | ~6.0/10 | | | | |
| | | | 98/2/A | < 1 m | ~6.0/10 | | | | |
| | | | | | | A | KCl Value% | | |
| | SD | | -40/4.2/A | > 8 m | 8.2/10 | 20.6/15.0 | 62.8/69.6 | KCl value and fluorescence units (A): Value at time 8/Value at time 0 | Thistle et al (1944) |
| | | | 0/4.2/A | > 8 m | 8.3/10 | 21.8/15.2 | 61.7/68.0 | | |
| | | | 40/4.2/A | > 8 m | 8.7/10 | 24.5/15.0 | 54.7/67.8 | | |
| | SD | | 75/3.7/CO | >32 w | ~7.2/10 | ~42.0/15.0 | ~52/69 | | |
| | | | 75/3.7/A | 32 w | ~6.0/10 | ~55.0/15.0 | ~38/69 | | |
| | | | 118/3.7/CO | <<64 d | ~1.8/10 | ~163.0/15.0 | ~18/69 | | |
| | | | 118/3.7/A | <<64 d | ~1.8/10 | ~142.0/15.0 | ~15/69 | | |
| | | | | | | A | KCl % | | |
| | AD | Whole Egg | 45/5/ | | | 31.3/26.0 | 61.8/71.9 | A: Fluorescence (units) & KCl values given as values at T=6m/Time=1m | White, et al. (1943) |
| | | | 60/5/ | | | 35.5/26.9 | 58.1/67.1 | | |
| | | | 75/5/ | | | 42.2/28.8 | 41.6/70.8 | | |
| | | | 75/5/A | | | 44.5/25.5 | 39.1/64.3 | Changes in quality assessed by fluorescence & KCl values | |
| | | | 75/5/V | | | 61.4/27.6 | 37.8/66.2 | | |
| | | | 75/5/CO | | | 38.6/25.5 | 72.2/71.6 | | |
| | | | 75/5/N | | | 46.5/28.9 | 51.6/70.4 | | |
| | | | 45/3/A | ~ 3 m | | | | Times given are times to obtain a fluorescent value of 26 which is the | ite & Thistle (1943) |
| | | | 45/5/A | ~ 3 m | | | | | |
| | | | 45/6.9/A | ~1.5 m | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

Eggs (continued)

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | AD | Whole egg | 80/3/A | ~ 17 d | | | | minimum level | |
| | | | 80/5/A | ~ 12 d | | | | of acceptability | |
| | | | 80/6.9/A | ~ 6 d | | | | | |
| | | | 110/3/A | ~ 46 d | | | | | |
| | | | 110/5/A | ~ 34 h | | | | | |
| | | | 110/6.9/A | ~ 26 h | | | | | |
| | | | | | A | | | | |
| | | Whole egg | 75/10.2-4.9/A | > 4 m | 69/100 | | | A: Cake score | Lorenz |
| | | Egg white solids | 75/ 4.8-3.3/A | > 4 m | 71/100 | | | A at time 0.83 | & Maga |
| | | | | | | | | A at time 0.92 | (1971) |
| | | | | | | | Percent Solubility | | |
| | | | 5-0/ | | | | 93-95 | Solubility after | Shrivastava, et al |
| | | | 73/ | | | | 67-75 | 410 days. | (1974) |
| | SD | pH 8.99 | 68/ | | | | 66.4/95.2 | Solubility after | Platka & |
| | | pH 6.43 | 68/ | | | | 92.0/96.3 | 12 months at 68°F | Schmidt |
| | | pH 5.62 | 68/ | | | | 92.8/95.0 | & 4 months at 99° | (1973) |
| | | pH 8.99 | 99/ | | | | 56.6/95.2 | F. Time t/Time 0' | |
| | | pH 6.43 | 99/ | | | | 68.9/96.3 | | |
| | | pH 5.62 | 99/ | | | | 69.3/95.0 | | |
| | | Tableted & | 64-68/5.33/A | | | | 81.0 | % solubility | Rudaskaya |
| | | packed in PE/ | 32-41/5.33/A | | | | 84.9 | after 1 year | & Orlova |
| | | Cellophane | 64-68/5.33/V | | | | 83.0 | | (1974) |
| | | " | 32-41/5.33/V | | | | 86.0 | | |
| | | Powder | 64-68/5.3-9.8/A | | | | 67.5 | | |
| | | " | 32-41/5.3-8.9/A | | | | 77.5 | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AD | air drying | SD | spray drying | A | air | Aw | water activity | d | days | CA | caking |
| DD | drum drying | Sun D | sun drying | CO | carbon dioxide | Atm | atmosphere | m | months | CO | color |
| FD | freeze drying | VD | vacuum drying | H | hydrogen | MC | moisture content | w | weeks | F | flavor |
| FMD | foam-mat drying | VFD | vacuum-foam drying | N | nitrogen | rh | relative humidity | y | years | O | odor |
| FSD | foam-spray drying | VPD | vacuum-puff drying | O | oxygen | T | temperature | IPD | in-package desiccant | TE | texture |

| Food Material | Method of Drying | Additional Treatment | Storage Conditions T(°F)/%MC/Atm. | Time required for appearance of the earliest defects (quality affected) | State of Other Factors at Time of Unacceptability or at Maximum Time Recorded: FLAVOR | COLOR | OTHERS | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| | FD | | 98/2.0 | < 4 w | 5.4/10 | | | Minimum level | Boggs, |
| | | | 72/2.0 | 16 w | 6.0/10 | | | of acceptability: | et al |
| | | | 39/2.0 | >16 w | 8.5/10 | | | 6.0. | (1946) |
| | FD | Whole egg | -29/1.8/ | >16 w | 9/10 | | | Limit of accept- | Fevold, |
| | | Whole egg | 98/1.8/ | 2 w | 6/10 | | | ability: 6 | et al. |
| | | Yolk + white | -29/ | >16 w | 9/10 | | | Moisture content | (1946) |
| | | Yolk + white | 98/ | < 8 w | 5.0/10 | | | Egg white 4.2% | |
| | | Yolk(-29°F) + white (98°F) | | >16 w | 8.6/10 | | | Egg yolk 1.3% | |
| | | White(-29°F) + yolk (98°F) | | < 3 w | 5.1/10 | | | | |
| Egg Mix | SD | Soybean Oil | 100/3/ | ~ 2 m | 7.0/11 | | | Minimum level of | Evans, |
| | | Corn oil | 100/3/ | ~ 2 m | 7.0/11 | | | acceptability: 7 | et al |
| | | Cottonseed oil | 100/3/ | ~ 2 m | 7.0/11 | | | Mixes contained 51% egg solids, 30% NFDM & 15% oil. | (1974) |
| | SD | Vacuum 30 in. | 100/2.0/V | <24 w (CO) | 5.5/6.0 | 4.8/6.8 | | Fresh whole egg 64.6% | Tuomy |
| | | 20 in. | 100/2.0/V | <24 w (F) | 4.5/6.0 | 5.6/6.8 | | Skimmed milk 30% | & Walker |
| | | | 100/2.0/A | <24 w (F) | 4.2/6.[illegible] | 5.5/6.8 | | Corn oil 4.8% | (1970) |
| | | Vacuum 30 in. | 100/2.5/V | >24 w (F) | 5.5/6.2 | 5.9/6.8 | | NaCl 0.6% | |
| | | 20 in. | 100/2.5/V | >24 w (F) | 5.3/6.2 | 6.1/6.8 | | Suggested limit of | |
| | | | 100/2.5/A | ~24 w (F) | 5.0/6.2 | 6.2/6.8 | | acceptability: 5.0 | |
| | | Vacuum 30 in. | 100/3.0/V | ~12 w (F) | 5.0/6.4 | 5.8/7.0 | | | |
| | | 20 in. | 100/3.0/V | ~12 w (F) | 5.0/6.4 | 6.0/7.0 | | | |
| | | | 100/3.0/A | <12 w (F) | 4.9/6.4 | 6.1/7.0 | | | |
| | | Vacuum 30 in. | 100/3.5/V | <12 w (F+CO) | 3.4/6.3 | 3.1/6.8 | | | |
| | | 20 in. | 100/3.5/V | <12 w (F+CO) | 4.0/6.3 | 3.4/6.8 | | | |
| | | | 100.3,5.A | < 6 w (F) | 3.9/6.3 | 5.2/6.8 | | | |
| | | Vacuum 30 in. | 100/4.0/V | < 6 w (CO) | 5.3/5.9 | 4.1/6.7 | | | |
| | | 20 in. | 100/4.0/V | < 6 w (CO) | 5.2/5.9 | 4.8/6.7 | | | |
| | | | 100/4.0/A | <12 w (F+CO) | 4.0/5.9 | 4.1/6.7 | | | |

AD air drying; DD drum drying; FD freeze drying; FMD foam-mat drying; FSD foam-spray drying; SD spray drying; Sun D sun drying; VD vacuum drying; VFD vacuum-foam drying; VPD vacuum-puff drying; A air; CO carbon dioxide; H hydrogen; N nitrogen; O oxygen; Aw water activity; Atm atmosphere; MC moisture content; rh relative humidity; T temperature; d days; m months; w weeks; y years; IPD in-package desiccant; CA caking; CO color; F flavor; O odor; TE texture

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